A Manual of
AUSTRALIAN SOILS

Second Edition

By C. G. Stephens

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This manual defines the character of Australian soils according to their Great Soil Groups. It provides a practical guide to the broad groups of soils occurring in Australia related to the accepted international Soil Groups. It is hoped that future broad-scale mapping of soils in Australia will follow this manual for uniformity and the common interpretation of maps.

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Foreword

In recent years a steadily increasing interest has been shown in the soil surveys and related investigations of the Division of Soils of the Commonwealth Scientific and Industrial Research Organization and cooperating State Departments. This interest has been displayed both by officers of other Departments attempting to carry out such surveys and by a much larger group who are finding soil survey data of considerable value in a number of fields, especially in projected settlement of dry, irrigated, and reclaimed lands, in engineering projects associated with aerodromes, roadways, and structural foundations, and in geological and geomorphological investigations, particularly those concerned with Tertiary and Quaternary formations.

An essential prerequisite for efficient action by any of these groups is the ability to recognize the different categories of soils. This manual, the first edition of which appeared in 1953, was prepared by Dr. C. G. Stephens, of the Organization's Division of Soils, to provide a brief introductory account of the system of soil classification in use in Australia before 1925, an elementary outline of the modern system of classifying soils on the basis of their morphology, and a classification of Australian soils.

The second edition of the manual has been brought up to date to cover the five additional great soil groups which have been identified in Australia in recent years—alpine humus soils, prairie soils, calcareous red earths, red and brown hardpan soils, and calcareous lateritic soils. Appropriate additions and some necessary amendments have been made to the text, tables, and illustrations. It is also recorded here that there is a little evidence that the equivalent of the chernozem soils of Eurasia and North America exists in very limited areas in Australia, but because this evidence is not conclusive, no relevant material is included in this book. There is also fragmentary information indicating the limited presence of yellow earths, one of the soils of wet tropical regions, but for the present this is likewise ignored.

Colour photographs and morphological descriptions of the profiles of Australian representatives of the great soil groups are designed to facilitate the recognition of individual soils. The selected bibliography of modern Australian soil surveys and related investigations has been brought up to date in the second edition. The manual should be of considerable assistance to teachers of agricultural science.

A MANUAL OF AUSTRALIAN SOILS

I. Introductory Notes on the Classification of Soils

(*a*) *Systems of Classification in Use in Australia before 1925*

From the very beginning of orderly agricultural and pastoral settlement in Australia, organized land surveying, where it was used as a basis of allotment and tenure, was accompanied by soil classification. The classification was made by land surveyors and with occasional minor modifications comprised three categories termed first, second, and third class land. These classes were based on a number of features supposed to reflect the fertility of the soil, including some of the species of the native vegetation, texture of the surface soil, natural drainage, and occasionally the nature of the underlying rock. Greatest emphasis was placed on the vegetation, particularly the species present, nature of the forest, grassland, or shrub formation, and apparent vigour of some of the plants. Species were not necessarily definitely identified and were most frequently referred to by a common or local name. Hence there appear in the records such terms as "stringybark" for a number of species of eucalypts, and other terms such as "whipstick" were applied to stunted forms of a number of plants of widely different orders. In a general way these three somewhat subjective land classes were supposed to be a reflection of the agricultural and pastoral potential of the land in terms of its natural grazing value, known suitable crops, and possible adaptable ones.

As land settlement progressed, geological mapping became more detailed and widespread because of the access provided by settlement and the destruction of forest cover. Hence there arose a marked tendency to adopt a geological basis for soil classification, particularly on developed land. However, this system never found great favour with Departments of Lands, but was adopted with various modifications by such authorities as Agricultural Departments, which steadily became involved in fertility aspects of agricultural production. They also needed some field system for the classification of farm lands to which they could readily refer both agronomic characteristics and data derived from the empirical chemical studies of the soil which came into vogue late in the nineteenth century. Geological maps provided a ready means of attempting this. Quite the most outstanding Australian contribution to soil classification based on geological and chemical features is that by Jensen (1914).*

The chemical system of soil classification, in contrast to chemical fertility studies, can hardly be said to have prospered alone outside the laboratory. Certain determinations such as content of soluble salts and hydrogen ion concentration, expressed on the pH scale of acidity and alkalinity, have been used for small

* Jensen, H. I. (1914).—"The Soils of New South Wales." (Govt. Printer: Sydney.)

projects in field mapping and classification of soils in terms of selected intervals of values. However, the arbitrary nature of these and other chemically based classes, which frequently cut across more apparent physical or natural categories found in the field, has clearly indicated that such chemical appraisals of soils are most usefully applied as an adjunct in the identification and estimation of soil profile features, such as lime content and similar properties used in soil classification based on morphology. This is apparent in the section on soil classification and morphology.

(*b*) *The Morphological System of Classification*

The morphological system of classification is based solely on an appraisal of the features found in the soil itself. The principal features are the colour, texture, structure, and consistence of the various horizons or layers found in the soil profile or section. In addition the presence, form, and approximate amount of organic matter, lime, gypsum, soluble salts, or any concretionary materials such as ferruginous, aluminous, siliceous, or manganiferous gravel and the nature of the parent material are noted. Simple chemical tests may have to be applied to confirm these identifications but most of them can generally be assessed by visible or tactile properties. The depth, subdivision, and arrangement of the A (eluvial), B (illuvial), and C (weathering) horizons are also significant, as is any evidence of a permanent or periodic water-table within the soil.

An orderly appraisal of the above properties is an obviously important objective assessment of any soil as an environment for plants of any character, or as an irrigation or engineering medium. It is on these major points of objectivity and derived utility that the strength of the morphological system rests. However, another very important feature is the readiness with which a great number of individual morphological appraisals of separate profiles may be sorted into distinct categories of similar soils referred to as soil types and these in turn be fitted successively into increasingly broader categories termed soil series, families, great soil groups, sub-orders, and orders. This taxonomic characteristic not only indicates the relationships of the soils, but is also of particular geographical use, greatly facilitating the mapping of soils at different degrees of detail, depending on the purpose of the survey in hand. Furthermore it has been found that certain of the categories, but particularly the great soil groups, sub-orders, and orders, are reproducible in widely separated areas and so enable soil assessments to be made, if necessary, on a continental scale. In brief, because of the different levels of categorization and the reproducibility of the units at any categorical level, it is possible to use the system to describe, assess, and map the soils of any area from a few acres to continental size.

This system had its origin in the work of Dokuchaiev and his associates in Russia towards the end of last century. Because of the language difficulty it remained practically unknown to the western world until the second decade of this century. Since then it has been modified and applied on an increasing scale in all continents, particularly in the United States of America where Marbut

(1927)* and Thorp and Baldwin (1938)† have done much to establish the essential taxonomic character of the categories used as subdivisions in the system of classification outlined above.

Recognizing the close association between the great soil groups and the different climatic zones in Russia, Dokuchaiev was the first to realize fully the frequently predominant role of climate in soil formation. The emphasis placed on the climatic factor by some workers, particularly Sibirtzev, has frequently caused the Russian system to be misquoted as a purely climatic system of classification. However, it is quite clear from their publications that the Russians realized clearly the function not only of climate, but also of vegetation, animals, topography, parent rock, and age of the land surface. Nevertheless they appear to prefer to regard the system as a genetic one, undoubtedly because they have been able to explain the morphological expression of the soils in terms of the above genetic factors. The morphological system, of necessity, precedes and is the basis of the genetic one. Since the demonstration of relationships is the very essence of classification it is logical that a sound morphological system will have a genetic explanation.

In 1924 J. A. Prescott, who had been appointed to the Chair of Agricultural Chemistry in the University of Adelaide and who in addition subsequently became Chief of the Division of Soils of the Council for Scientific and Industrial Research, made the first effective introduction to Australia of the Russian system of classification. In a large number of soil survey projects undertaken by the Division since that time, the system, with Australian and United States elaborations, has been used almost exclusively. At present there are available numerous reports on soil survey projects ranging from irrigation settlements and dry-land agricultural areas, covered in the detail afforded by soil series, type, and phase mapping, to Prescott's own continental compilations of the Australian expression of the broader great soil groups. Some State Departments, particularly in Western Australia and Victoria, have also compiled similar surveys. At the end of this manual there is a selected bibliography containing practically all such Australian soil studies.

As noted above the classification consists of six increasingly broader categories termed soil types, soil series, soil families, great soil groups, soil sub-orders, and soil orders. This categorization is similar to the botanical system which passes from species through genera, families, orders, and classes to the divisions of the flora, and just as morphology is the basis of the categories of the flora, so morphology is the proper basis of the soil categories. Naturally there is an almost infinite number of morphological attributes to consider and it is essential to know their relative importance. The attributes are not by any means independent of one another so it is essential to have at a higher level the attributes that include or influence strongly those recorded at lower levels.

* Marbut, C. F. (1927).—A scheme for soil classification. First Int. Congr. Soil Sci. Proc. Pap. **4**: 1-31.

† Thorp, J., and Baldwin, M. (1938).—New nomenclature in the higher categories of soil classification as used in the U.S.D.A. *Proc. Soil Sci. Soc. Amer.* **3**: 260-8.

TABLE 1

THE TAXONOMY OF SOIL CLASSIFICATION: PRINCIPAL DETERMINANT MORPHOLOGICAL ATTRIBUTES OF THE DIFFERENT CATEGORIES

VI. Soil Orders	V. Soil Sub-orders	IV. Great Soil Groups	III. Soil Families	II. Soil Series	I. Soil Types
Differences in orders are associated with the presence or absence of lime and/or gypsum in the A and/or B horizons	Differences in sub-orders are associated with the position of horizons of organic matter, clay, sesquioxides, lime, and gypsum	Differences in great soil groups are associated with differences in profile colour and texture and the presence or absence of hydromorphic, calcimorphic, haemomorphic, phytomorphic, halomorphic, and palaeomorphic features in the profile	Differences in families are associated with differences in depth of the solum and differences in structure, consistence, and mottling of the B horizon	Differences in series are associated with differences in parent materials	Differences in types are associated with differences in texture of the A horizon and simultaneously with accompanying minor differences in the B and C horizons

Definitions

Mesomorphic soils.—Soils in which the profile features are associated with normal parent materials and well-drained conditions (syn. automorphic).

Hydromorphic soils.—Soils in which the morphology of the profile is significantly influenced by the permanent or periodic water saturation of parts of the profile, this being reflected in mottled or drab colouration.

Calcimorphic soils.—Soils in which the morphology of the profile is significantly influenced by the high lime content of the parent material, this being reflected in rather undifferentiated mineral profiles and the presence of lime at shallow depths.

Haemomorphic soils.—Soils in which the morphology of the profile is significantly influenced by the ferric oxide set free by weathering from the soil parent material, this being reflected by red colouration and flocculated soil profiles (syn. ferrimorphic).

Phytomorphic soils.—Soils in which the morphology of the profile is significantly influenced by an unusually large accumulation of organic matter, this being reflected in peat formation.

Halomorphic soils.—Soils in which the morphology of the profile is significantly influenced by a previous or prevailing accumulation of saline materials, this being reflected either in columnar illuvial horizons and their remnants or by the presence of soluble salts.

Palaeomorphic soils.—Soils in which the morphology of the profile is significantly influenced by climatic and geomorphic conditions no longer operating, this being reflected in the presence of laterite and/or its companion materials in the soil profile.

Polymorphic soils.—Soils in which the morphology of the profile is significantly influenced by two or more of the above morphological expressions.

Amorphic soils.—Soils in which the morphology of the profile is not significantly influenced by any of the above morphological expressions.

The determinant morphological attributes of each of the categories are listed in Table 1. No category is a basic one; in fact the basic unit is the soil profile itself and it is possible to proceed directly by sorting from a collection of soil profiles to any of the six categories without passing through one or more categories either below or above.

In some soil surveys of a very detailed character the soil type has been arbitrarily split into what are termed soil phases. These are useful agricultural subdivisions having no taxonomic standing and largely based on subdivisions according to the depth of the surface soil or a feature of some other horizon. In addition in some early surveys the soil type was not defined on strict morphological grounds, suitability for an existing or potential crop being used to broaden or restrict the definition of the soil types as mapped. This is a technological rather than scientific procedure and causes the soil classification used in the survey to be somewhat vitiated as a comprehensive basis for crop or other correlations.

TABLE 2

CATEGORIES USED IN SOIL CLASSIFICATION

Solum Classes (I and II) Soil Orders (*A* and *B*) Soil Sub-orders (*a-i*) Great Soil Groups (1–45)	Shown in Table 3
Soil Families Soil Series Soil Types Soil Phases	Not shown in Table 3

(*c*) *A Classification of Australian Soils*

Table 2 sets out a convenient arrangement of solum classes, soil orders, sub-orders, and great soil groups, the latter being successively numbered so that reference to the morphological descriptions numbered 1-46 in Section II can readily be made. In Table 3 the great soil groups are arranged in the categories of Table 2.

TABLE 3

GREAT SOIL GROUPS ARRANGED UNDER SOLUM CLASSES, SOIL ORDERS, AND SUB-ORDERS

I. Solum Undifferentiated

1. Alluvial soils: showing only sedimentary horizons (amorphic)
2. Skeletal soils: shallow stony soils with no significant profile development (amorphic)
3. Aeolian sands: with no significant profile development (amorphic)

TABLE 3 (*Continued*)

II. Solum Differentiated

A. Pedalfers	*B.* Pedocals
a. Solum dominated by acid peat or peaty eluvial horizon	*e.* Solum dark coloured and slightly acid to neutral in eluvial horizons, calcareous illuvial horizons
4. Moor peats (phytomorphic)	21. Black earths (mesomorphic)
5. Alpine humus soils (mesomorphic)	22. Wiesenboden (hydromorphic)
6. Moor podzol peats (polymorphic)	23. Brown forest soils (calcimorphic)
7. Acid swamp soils (polymorphic)	24. Rendzinas (calcimorphic)
b. Solum acid, and with organic, sesquioxide, and sometimes clay illuvial horizons	25. Ground-water rendzinas (polymorphic)
8. Podzols (mesomorphic)	26. Fen soils (polymorphic)
9. Ground-water podzols (hydromorphic)	*f.* Solum saline or showing post-saline structure in the illuvial horizon
c. Solum acid, and with clay and sesquioxide illuvial horizons	27. Solonchak (halomorphic)
10. Lateritic podzolic soils (polymorphic)	28. Solonetz (halomorphic)
11. Grey-brown podzolic soils (mesomorphic)	29. Solodized solonetz (halomorphic)
12. Brown podzolic soils (mesomorphic)	30. Soloth (halomorphic)
13. Red podzolic soils (mesomorphic)	31. Solonized brown soils (polymorphic)
14. Yellow podzolic soils (mesomorphic)	*g.* Solum with slightly acid to neutral eluvial horizons and calcareous illuvial horizons
15. Meadow podzolic soils (hydromorphic)	32. Red-brown earths (mesomorphic)
d. Solum acid to neutral and lacking pronounced eluviation of clay	33. Brown earths (mesomorphic)
16. Krasnozem (haemomorphic)	34. Brown soils of light texture (polymorphic)
17. Lateritic krasnozem (polymorphic)	35. Calcareous red earths (polymorphic)
18. Lateritic red earth (polymorphic)	36. Grey calcareous soils (calcimorphic)
19. Terra rossa (calcimorphic)	*h.* Solum with neutral to alkaline weakly developed eluvial horizons and calcareous and/or gypseous illuvial horizons
20. Prairie soils (mesomorphic)	37. Grey soils of heavy texture (hydromorphic)
	38. Brown soils of heavy texture (mesomorphic)
	i. Solum with deflated slightly acid to alkaline eluvial horizons and calcareous and/or gypseous illuvial horizons
	39. Desert loams (mesomorphic)
	40. Grey-brown and red calcareous desert soils (calcimorphic)
	41. Red and brown hardpan soils (hydromorphic)
	42. Desert sand plain soils (polymorphic)
	43. Calcareous lateritic soils (polymorphic)
	44. Stony desert tableland soils (polymorphic)
	45. Desert sandhills (mesomorphic)

Definitions

Pedalfers.—Soils in which lime carbonate does not accumulate in any part of the profile, but such carbonate as may have been present in the parent material is continually in process of disappearance from the soil profile.

Pedocals.—Soils in which, regardless of the presence or absence of lime carbonate in the parent rock, lime carbonate (and/or sulphate) has accumulated in the soil during the progress of soil making and as a result of the soil-forming processes (Marbut*).

* MARBUT, C. F. (1951).—"Soils: Their Genesis and Classification . . . A memorial volume of lectures given in the Graduate School of the United States Department of Agriculture in 1928." 134 pp. (Soil Science Society of America: Madison.)

II. Description of Australian Representatives of the Great Soil Groups

In this section the soils illustrated in Figures 1-46 by reproductions of colour photographs are described. These soils are Australian representatives of the great soil groups and their numerical order follows that set out in Table 3.

1. *Alluvial Soils*

Fig. 1

Morphology.—Alluvial soils are restricted to alluvium so juvenile that soil-forming processes other than organic matter accumulation have not had time to function. Hence, although these soils may show considerable variation in the profile with depth, especially in textural character of apparent horizons, they have no true pedologic horizons. The sedimentary layers that do exist in these soils can vary very greatly in a number of characters, including texture, stoniness, depth, colour, and lime content, but they generally are fairly clearly defined at their contact with each other and not infrequently some layers show evidence of current bedding. In general the differences between pedologic horizons and sedimentary layers are not difficult to detect. Not infrequently, some of the layers in the profile show evidence in their content of organic matter of having been former surface soils buried under later deposits. Sometimes the buried or fossil soils show evidence of pedologic horizons.

The alluvial soil illustrated in Figure 1 shows uniform-textured, deep alluvial material with no evidence of profile development. It occurs on the levee bank of the Katherine River near Katherine, in the Northern Territory.

Genesis.—Profile genesis in alluvial soils is entirely sedimentary, the different layers being due to successive additions of material different or similar to that lower in the profile. These additions are derived by deposition from bodies of water, still or moving at various rates, the texture of the material being determined largely by the velocity of the water.

Occurrence.—Alluvial soils occur in all parts of Australia. They are associated not only with rivers but also with lacustrine, deltaic, and alluvial cone formations. Where they are associated with rivers and creeks they normally occur on the levee banks and the first terraces of the streams, older terraces, if they exist, normally being occupied by soils showing pedologic horizons.

Utilization.—Alluvial soils are used probably for all forms of agricultural and pastoral activity in Australia. However, they are greatly valued in sugar-cane production, for various forms of horticulture, especially hop-growing in Tasmania, vegetable production, and other forms of intensive agriculture, particularly where irrigation is practised.

2. *Skeletal Soils*

Fig. 2

Morphology.—Skeletal soils are essentially stony or gravelly soils showing no profile development other than organic matter accumulation in the surface. Normally they are shallow and contain a large proportion of coarse-textured material in the form of fragmented rock, which may show some degree of weathering. The lack of eluvial and illuvial horizons is the essential feature but characteristically they are non-arable.

The skeletal soil illustrated in Figure 2 shows characteristic stoniness and lack of profile differentiation apart from a little organic matter accumulation in the surface soil. It is from Brocks Creek, in the Northern Territory.

Genesis.—Skeletal soils are essentially nascent soils: apart from the initiation of weathering and accumulation of organic matter, little or no profile development has taken place. These conditions may be due to recent exposure of the parent material to the action of the soil-forming processes or more commonly to the forces of natural erosion being sufficient to remove finer-textured soil material as fast as it is formed. Hence skeletal soils are normally found where weathering and erosion are in equilibrium.

Occurrence.—Skeletal soils are found throughout Australia wherever topography is rugged enough to ensure that natural erosional processes are active enough to remove soil; that is, principally on the crests and steeper-sloping parts of hilly and mountainous areas. Certain rocks rather resistant to weathering may give rise to skeletal soils under gentler topographic conditions.

Utilization.—Skeletal soils are normally little used. Apart from their retention under natural forest for purposes of timber production, their major use is for sheep- and cattle-grazing where they occur with suitable vegetative cover, which preferably includes some grass species. In restricted areas in southern Australia subterranean clover pastures may be seeded by hand on uncultivated skeletal soils and then top-dressed periodically with superphosphate; such utilization is normally accompanied by an increased carrying capacity per acre.

3. *Aeolian Sands*

Fig. 3

Morphology.—Aeolian sands formed into dunes during recent times show no profile development beyond some accumulation of organic matter in the surface where they have been fixed by vegetation. Where the sands are still unvegetated the organic surface is missing. Generally these sands are calcareous, deep, and very coarse-textured and are usually of a light yellow to neutral colour.

The profile shown in Figure 3 shows an undifferentiated aeolian calcareous sand with some accumulation of organic matter in the surface foot of soil. It is from the South Australian coast east of Port Macdonnell.

Genesis.—The genesis of aeolian sands with undifferentiated profiles is rudimentary. The material is usually derived from beaches and piled up nearby by wind action. The lime in the soil is derived largely from fragmented sea shells

and other marine organisms, and may show some effects of solution and redeposition in the profile in the form of root casts and consolidated layers.

Occurrence.—These undifferentiated aeolian sands occur commonly around the Australian coast almost exclusively near beaches. They are sometimes heavily clothed with coastal shrubs or grass and often unvegetated and mobile.

Utilization.—In certain localities, notably on the islands of Bass Strait and parts of the South Australian coast, these aeolian sands are clothed largely by a grassy sward. Such dunes are used for the grazing of sheep and cattle and, although they are subject to coast disease due to deficiencies of cobalt and copper, successful utilization is made possible either by intermittently grazing stock elsewhere or by supplying the necessary cobalt and copper. In other localities where conditions for grazing are not so favourable, grazing is incidental and the danger of wind erosion significant, particularly where better land lies near the dunes and is liable to be buried by moving sand.

4. *Moor Peats*

Fig. 4

Morphology.—Moor peats show little apparent horizon development, the greater part of the profile consisting predominantly of organic matter, black or nearly black in colour, generally at or near saturation with water, and gradually increasing in fineness with depth. The upper part of the profile contains a significant amount of generally lighter-coloured fibrous material and in the lower part some mineral matter, frequently clayey, is often apparent in and below the peat. There is a large variation in depth, ranging from a few inches up to about 3 ft or more. The shallow soils are associated with stony and boulder areas, usually on slopes, and the deeper profiles with areas of gentler relief, sometimes with restricted drainage. The parent material of these soils is predominantly organic matter but there is some contribution from the underlying rock. The peats rest on a wide variety of such rocks and their detrital products, and in the latter thin iron-pans may sometimes be observed in rather fine detrital material below the organic profile.

The moor peat profile illustrated in Figure 4 shows the nature of the peat in the upper and lower parts of the profile and the water-table frequently found in these soils. The profile illustrated is from near the Great Lake, in Tasmania.

Genesis.—Profile genesis consists simply of a slow but positive accumulation of organic matter from the associated alpine flora and its gradual metamorphosis by humification under an acid regime from a fibrous to a virtually structureless mass.

The relationships of the moor peats to environmental features reveal a major role of the temperature factor. These soils occur in Australia on mountains where the leaching factor, if expressed as a function of precipitation and evaporation, has values corresponding to the podzol and podzolic soil region. The differential factor associated with the moor peats is low mean annual temperature. Hence they are normally found at considerable elevations and their organic matter

accumulation is a direct consequence of low biological and chemical activity, which precludes decomposition and oxidation of plant residues as they are shed by the flora. Poor drainage, as with peats generally, enhances the accumulation.

Occurrence.—On the highest mountains and plateaux in Tasmania, Victoria, and New South Wales; that is, above the winter seasonal snow-line, which ranges from about 3000 ft in southern Tasmania to about 4500 ft on the Kosciusko massif, in New South Wales.

Utilization.—In the summer months, when these soils are free from snow, cattle and sheep are frequently moved up from lower lands for a period of grazing on the natural vegetation of the moor peats and their associated skeletal soils.

5. *Alpine Humus Soils*

Fig. 5

Morphology.—Alpine humus soils are characterized by a marked accumulation of organic matter in the surface horizons of profiles otherwise exhibiting little horizon development. The organic matter, which is fibrous near the surface and more friable below, confers a very dark grey to brownish black colour on the A horizons, which often reach to depths greater than 12 in. These surface soils are generally peaty loams in texture and have a friable crumbly structure. The lower part of the profile, passing gradually from the A to the C horizon, is grey, yellow-grey, or grey-brown in colour, coarser in texture, and with grit and stone fragments often quite evident. Discrete mineral fragments from the weathering rocks below are usually discernible and give a speckled appearance to the soil. Frequent stone lines in the profile and sometimes surface contortions are evidence of some solifluction on steeper sites. In these soils in Tasmania a thin iron-pan sometimes occurs in the lower part of the profile. Parent material of the soils is very variable.

The profile illustrated in Figure 5 is from Mt. Buffalo in Victoria.

Genesis.—As with the moor peats the accumulation of organic matter in the surface horizons, although to a lesser degree, is due to the slow rate of decomposition of litter from the associated flora under the low-temperature conditions prevailing for much of the year on the elevated landscape where these soils occur. The decrease in texture and the increase in grittiness and discrete mineral fragments down the profile are taken as evidence of predominant physical weathering. The thin iron-pans in Tasmania represent the first stage of podzol formation.

Occurrence.—The soils occur on the highlands of south-eastern Australia. They lie, with some variations due to the effects of aspect, above about 3000 ft in Tasmania and 4000 ft in Victoria and New South Wales.

Utilization.—As with the associated moor peats the natural vegetation on these soils is used for the summer grazing of sheep and cattle. There is an increasing emphasis on the conservation of this alpine and subalpine landscape because it is the source of practically all the water used for irrigation and the generation of hydroelectric power in south-eastern Australia.

6. *Moor Podzol Peats*

Fig. 6

Morphology.—In general the profile of these soils consists of a somewhat masked ground-water podzol with a fibrous peat accumulation of some depth on the surface. This peat represents an A_0 horizon developed under conditions of restricted drainage with the water-table frequently at the surface. The A_1 horizon beneath is composed of a siliceous horizon darkened by considerable quantities of organic matter, and the A_2 horizon, also siliceous in character, is lighter in colour but frequently significantly darkened by organic matter in a very fine state of subdivision and being transported to the organic and siliceous B_1 hardpan horizon below. The B_2 and C horizons below are very variable in character, ranging from mottled clay to quartzitic rubble embedded in a matrix of weathered rock and soil. Frequently quartzitic gravel occurs throughout the profile, including the A_1 horizon. Where these soils are shallow, as they frequently are on slopes and on hills formed of quartzitic rocks, stone and boulders frequently protrude through the soil on the crest of the rises.

The profile illustrated in Figure 6 shows the peaty surface and A horizons of a moor podzol peat from near Mawbanna, in Tasmania.

Genesis.—Profile genesis consists of a polygenetic phenomenon. The podzol character is due to the leaching and formation of horizons of accumulation, including hardpan genesis, frequently under the influence of ground water. The hardpan accentuates the already restricted drainage, causing intermittent waterlogging of the A horizons and thus giving rise to anaerobic conditions favourable to the accumulation of a deep, peaty A_0 horizon.

The environmental relationships of these soils are fairly complex. As indicated above, at least restricted secondary drainage is required for their formation following development of a hardpan under conditions giving rise to podzolization. Thus these soils are associated with areas of perhumid climate and the accumulation of the surface peat is favoured by cold as well as wet conditions. The peat is composed largely of the remains of a cyperaceous plant, *Gymnoschoenus sphaerocephalus*, commonly termed button grass, and the open soil-plant-topography landscapes are generally referred to as button grass plains. Because of the nature of the pedogenetic process, involving the removal of bases and the accumulation of plant remains, these soils are extremely acid, frequently having pH values less than 4 in the surface peat.

Occurrence.—Moor podzol peats occur practically entirely in Tasmania, and there largely in the severe climatic regions of the west and south-west coastal and mountainous regions. There are small occurrences in north-east Tasmania and a minute development of related incipient soils on the Cape Otway Peninsula in Victoria.

Utilization.—Apart from a little incidental grazing by store cattle these soils are not used at all. Attempts at pasture production have been made, so far with practically no success.

7. *Acid Swamp Soils*

Fig. 7

Morphology.—Acid swamp soils consist of a variable mixture of organic and mineral matter of acid reaction under the influence of a water-table that periodically is at, above, or near the surface of the profile. Surface soils are variable in depth and range from peaty sands, sandy loams, and loams to true peats of a more or less fibrous character. The surface horizon is generally black or dark grey in colour and the organic content decreases with depth, the lower mineral part of the profile, under the influence of the water-table, being grey or mottled in colour. Textures of the subsoil horizons are very variable.

The profile illustrated in Figure 7 shows a reclaimed acid swamp soil with a surface horizon of about 1 ft of peat overlying grey sand. It is from Mt. Compass, in South Australia.

Genesis.—Being hydromorphic in nature, acid swamp soils owe their organic character and grey or mottled subsoils to the partial or complete anaerobic regime imposed by the water-table. Under such conditions certain swamp-loving species of plants flourish and provide organic matter that is not quickly decomposed and thus accumulates as peat. The drab or mottled colours of the subsoil are the result of complete or partial exclusion of oxygen from the lower part of the profile, which may be permanently or periodically saturated by water.

Occurrence.—These soils occur in suitable enclosed topographic situations throughout humid and subhumid Australia. They are most common in the wettest areas and their occurrence is particularly favoured by the conditions prevailing in dune troughs and related coastal formations in southern Australia.

Utilization.—Where topographic situations are favourable acid swamps are commonly drained and utilized for various forms of primary production. Intensive pasture production for dairying and vegetable-growing, especially potatoes, are particularly favoured means of utilizing swamp lands.

8. *Podzols*

Fig. 8

Morphology.—In Australian podzols the superficial organic A_{00} horizon consists of a thin and variable scatter of leaves, twigs, and bark from the predominantly sclerophyll forest or heath vegetation found on these soils. The decomposed organic A_0 horizon is largely missing but invariably there is a pronounced accumulation of organic matter in the A_1 horizon, rendering it dark grey or speckled in colour. The A_2 horizon is variable in depth and light grey, or nearly so. Textures in the A horizon are generally sand or sandy loam but finer textures do occur. The B_1 horizon consists of an accumulation of organic matter or oxides of iron or both, either soft or pan-like in form and coloured brown or black, or both. The B_2 horizon is variable in texture, from sand to clay, and often somewhat mottled in colour with yellow and grey predominant. Parent materials, and thus C horizons, are variable in character and range from leached aeolian sands to sedimentary and igneous rocks.

The profile illustrated in Figure 8 shows the characteristic features of the A horizons and the accumulation of iron and organic matter in the B horizon of a podzol. The photograph is of a profile at Furner, in South Australia.

Genesis.—The profile is formed as a result of the movement of clay, sesquioxide, and organic matter downward in the profile following the removal of cations in drainage water. The clay, sesquioxides, and organic matter go into molecular or colloidal solution in the upper part of the profile, where conditions are quite acid, and are deposited lower in the profile, forming the B horizons described above. Since the removal of bases is a necessary prerequisite for podzol development these soils are found only in humid or perhumid areas where the leaching factor is sufficiently high. They occur on a wide range of parent materials but persist into areas of lower leaching factor quite considerably on sandy and siliceous rocks. Topography does not appear to influence their development greatly and the role of the Australian sclerophyll vegetation as a factor in their formation has never been investigated. In the main they are mature soils in equilibrium with current climatic conditions.

Occurrence.—Podzols occur occasionally in the most humid parts of all mainland States. They are quite common in Tasmania.

Utilization.—Generally speaking the utilization of podzols with introduced crops and pastures has proved difficult. Under natural conditions they are generally covered by relatively poor forest and heaths and when planted to exotic trees such as *Pinus radiata* and *P. pinaster* they frequently require superphosphate and trace elements to enable an economic forest to be developed. Under pasture and other crops such as apples they have proved difficult because of their acidity, low fertility status, pan formation in the subsoil, and limited moisture supply in periods of dry weather.

9. *Ground-water Podzols*

Fig. 9

Morphology.—In ground-water podzols the A_{00} and A_0 horizons are often more or less superficially present, particularly the A_{00}, depending on the vigour of the associated vegetation. The A_1 horizon is generally coarse-textured, most frequently sand, is rendered dark grey or speckled by coarse organic matter, and is frequently more than 6 in. thick. The A_2 is of similar texture, largely lacks organic matter, and is therefore light grey to white in colour, and sometimes several feet thick. The B_1 and B_2 horizons consist of more or less indurated accumulations of organic matter and iron compounds, sometimes singly, sometimes together, and, ranging from black to brown in colour, often referred to as "coffee rock". Below, the B horizon may continue as a mottled layer of clay or coarser-textured mineral horizon passing gradually to the C horizon. The water-table, which is an essential feature associated with these soils, is commonly found at a point in the profile below the B_1 horizon but occasionally, by saturation of the soil above the indurated pan, it rises to the surface.

The profile illustrated in Figure 9 shows the thick A horizon and very well-developed organic and iron accumulations of the B horizon of a ground-water podzol. The photograph is of a soil near Smithton, in Tasmania.

Genesis.—The B horizons of organic matter, iron compounds, and clay, if present, are due to eluviation from the A horizons. The pan-like accumulation of the B_1 and B_2 is due in part to association with the usual position of the top of the ground water, which largely determines their location and assists in times of heavy rain in the accumulation of a temporary water-table on top of the pan. These soils are found in association with podzols and podzolic soils, especially on arenaceous parent materials situated in topographic positions with permanent ground water near the surface. Their surface A_{00} and A_0, and to a lesser degree the A_1, horizons are influenced by the associated vegetation, thicker and more definite accumulations being associated with forest types and lesser accumulations with heaths and shrubs.

Occurrence.—Ground-water podzols occur in areas influenced by ground water in the more humid parts of all States of Australia.

Utilization.—Various attempts at pasture establishment have been made on these soils, with little success to date. They are of high acidity and low fertility, and have water relations in the surface horizons varying between saturation in wet weather and extreme droughtiness in prolonged periods of dry weather.

10. *Lateritic Podzolic Soils*

Figs. 10*a*, 10*b*

Morphology.—The essential feature of the relict lateritic soils of Australia is the presence in the profile of a horizon of nodular, pisolitic, or massive laterite. Beneath the laterite normally, but not invariably, occur mottled and white or nearly white kaolinitic clay horizons. These are frequently termed mottled zone and pallid zone. In addition sometimes there occurs in this portion of the profile an intermittent horizon of siliceous material known by the term "billy". These clay and siliceous horizons are usefully termed companion materials. Disintegrated laterite with some soil material and organic matter commonly forms the present A horizons of these soils but remnants of the original surface horizons also occur. These latter are essentially podzolic in character, consisting principally of light-coloured and coarse-textured material with which is associated some organic matter in the A_1 horizon and more rarely an organic-stained B_1 horizon.

Figures 10*a* and 10*b* show respectively a relict podzolic type of profile with lateritic gravel and mottled clay beneath and a truncated type of profile in which the exposed laterite has contributed to surface soil formation. The first is from north of Katherine, in the Northern Territory, and the second from the Dundas Tableland, near Coleraine, in Victoria.

Genesis.—The occurrence of Australian lateritic soils on tableland relics and related land forms of Pliocene age indicates that they are essentially relict soils formed on flatter surfaces and under more humid conditions than those in which they now occur. The laterite and companion materials were formed under the

influence of a seasonally fluctuating water-table, which caused the deposition of iron and aluminium oxides in the form of laterite and deprived the kaolinitic horizons below of part or all of their colour by the removal of iron in solution.

Occurrence.—These soils occur in all States of Australia, most commonly in the more humid areas, but relict formations of characteristic shape and capped with lateritic ironstone occur in quite arid regions.

Utilization.—Lateritic podzolic soils under natural conditions are covered by forest, savannah woodland, and heath formations. The forests are a source of timber, and sheep and cattle are grazed on the savannah woodlands and heaths. Improved sown pastures have, of recent years, been extensively produced on the truncated version of these soils, subterranean clover as a pioneer legume, superphosphate in liberal quantities, and various trace elements being required for successful establishment. In restricted areas where fertility was not so low, earlier agricultural establishment with a range of pastures and arable crops had been relatively successful.

11. *Grey-brown Podzolic Soils*

Fig. 11

Morphology.—In grey-brown podzolic soils the A_{00} horizon, which is usually very poorly developed, consists of leaf, twig, bark, and stem residues from trees, shrubs, and grasses and the A_0 horizon is not present to a perceptible degree. The A horizon is generally of light to medium texture, grey-brown or brownish grey in colour, and slightly darkened in the A_1 portion to a depth of 3-4 in. by organic matter. The B horizon is usually a clay in texture, of nutty to blocky structure, brown to yellow-brown in colour, and often mottled with some grey or grey-brown, particularly in the lower portion. The C horizon is very variable in character, the parent material consisting of a wide variety of rocks but excluding the most siliceous and the most ferruginous.

The profile illustrated in Figure 11 shows the colour and structural characteristics of the A and B horizons. The photograph is of a soil near Lucindale, South Australia.

Genesis.—The contrast in texture between the A and B horizons is due to eluviation of clay from the A and its deposition in the B horizon, which has a structure determined by its moderately low base status, lime being absent and cations being partly removed from the profile by leaching. The frequent mottled colour of the lower portion of the B horizon is determined by the frequency of occurrence of temporarily restricted drainage to which this soil is subject in times of sufficiently heavy rainfall.

These soils form on an intermediate range of rocks under various vegetative conditions and in topographical situations that, although well drained externally, do not prevent some degree of internal drainage restriction. They appear to be in equilibrium with current climatic conditions.

Occurrence.—These soils occur in the humid parts of Tasmania, southern New South Wales, Victoria, and South Australia.

Utilization.—Grey-brown podzolic soils are used practically entirely for pastures. Some of these pastures are composed of native species but over large areas they consist of subterranean clover with or without introduced grasses. Normally such sown pastures are top-dressed with superphosphate each autumn.

12. *Brown Podzolic Soils*

Fig. 12

Morphology.—In the brown podzolic soils the A_{00} horizon, which is usually very poorly developed, consists of leaf, twig, bark, and stem residues from trees, shrubs, and grasses, and the A_0 horizon is not present to a perceptible degree. The A horizon is generally of light to medium texture, brown in colour and darkened in the A_1 portion to a depth of 2-3 in. by organic matter. The B horizon is usually diffusely defined, a clay or clay loam in texture, of nutty to blocky structure, yellow-brown, brown, or occasionally reddish brown in colour. The C horizon is very variable in character, the parent material consisting of a variety of rocks or unconsolidated sediments.

The profile illustrated in Figure 12 shows a brown podzolic soil from Wokalup, in Western Australia. The colour and diffuse definition of the horizons are apparent.

Genesis.—The contrast in texture between the A and B horizons is due to eluviation of clay from the A and its deposition to form the B horizon, which has a structure determined by its base status, which is usually moderately low, leaching being sufficient to remove lime entirely, and exchangeable cations largely, from the profile. Drainage is usually sufficiently good to prevent significant mottling in the B horizon.

These soils form on a rather more restricted range of parent material than the other podzolic soils, being generally found on intermediate rocks in well-drained situations. There is no evidence of a significant role of any particular vegetation type and they appear to be in equilibrium with current climatic conditions.

Occurrence.—Brown podzolic soils have been observed in the moister parts of Tasmania and Western Australia. They may occur in the remainder of southern Australia.

Utilization.—In southern Tasmania these soils are used for pasture production and apple-growing, to which they appear to be well adapted.

13. *Red Podzolic Soils*

Fig. 13

Morphology.—In red podzolic soils the organic A_{00} horizon consists of leaves, twigs, and bark from trees and frequently some grass remnants as a thin to moderate cover. There is little or no apparent A_0 horizon. The A_1 horizon is generally coarse-textured and fairly thick but varies from 1 to 6 in. in depth. It is generally grey in colour and overlies a similar-textured, somewhat lighter-coloured A_2

horizon, usually a neutral shade but, as with the A_1, sometimes with a distinct light red or brown component. The B horizon consists of a friable red clay of granular to nutty structure and of very variable depth. The C horizon is bright but very variable in colour and other characteristics. Parent materials are variable but generally do not include the most siliceous rocks low in iron minerals.

The profile illustrated in Figure 13 is a red podzolic soil from the Burdekin Valley, in Queensland. It shows the characteristic features of the A and B horizons. The lighter-coloured C horizon is visible in the bottom of the pit.

Genesis.—The contrast in texture between the A and B horizons is due to eluviation of clay from the A horizons and its deposition to form the B, which has its structure maintained by the flocculating action of the free hydrated ferric oxide present. Leaching is sufficient to prevent the accumulation of lime in the profile.

These soils form on all but the most siliceous and least ferruginous rocks in areas where the rainfall is adequate to leach the profile for at least portion of the year. They occur under a wide range of vegetative conditions from tropical rain-forest to long and short grass savannah woodland. Their formation is not favoured by locally over-moist sites, where they tend to be replaced by yellow podzolic or other soils. They are generally mature soils in equilibrium with prevailing climatic conditions.

Occurrence.—Red podzolic soils occur in the more humid or seasonally humid parts of all States of the Commonwealth but are not particularly frequent in the cooler areas of Tasmania and Victoria.

Utilization.—Red podzolic soils are used extensively for the grazing of sheep and cattle on both natural and improved pastures, the latter being largely limited to southern Australia. Some arable crops, including wheat and oats, are also grown and fruit-growing, including apples, pears, and small fruits, is well established on these soils in southern Australia.

14. *Yellow Podzolic Soils*

Fig. 14

Morphology.—In the yellow podzolic soils the organic A_{00} horizon consists of leaves, twigs, and bark from trees and frequently some grass remnants, usually as a thin, scattered cover. There is no significant A_0 horizon. The A_1 is generally coarse-textured and is usually fairly thick but varies from 1 to 6 in. in depth. It is grey in colour and overlies a similar-textured, lighter-coloured A_2 horizon, usually of neutral shade but sometimes with a light yellow component. The B horizon consists most frequently of a yellow clay of granular to angular nutty structure. However, colour is frequently yellow-brown and often slightly mottled, and texture, on siliceous parent material, a sandy clay or sandy clay loam. The C horizon is very variable in character and these soils form on a wide variety of parent materials.

The profile illustrated in Figure 14 is a yellow podzolic soil from Crafers, in South Australia. It shows the features of the A, B, and C horizons of these soils.

Genesis.—The contrast in texture between the A and B horizons is due to eluviation of clay from the A horizons and its deposition to form the B. This process is carried on under conditions such that the whole soil is leached and hence no free lime is found in the solum.

These soils form on a wide variety of parent materials in areas where the rainfall is adequate to leach the profile for at least a portion of the year. They occur not only under sclerophyll and wet sclerophyll forest but also to a marked degree under savannah woodland with either short or tall grass. Their formation is not favoured by locally arid sites such as the tops of hills, where they are frequently replaced by red podzolic soils. They appear to be generally mature soils in equilibrium with prevailing climatic conditions.

Occurrence.—Yellow podzolic soils occur in the more humid or seasonally humid parts of all States of the Commonwealth.

Utilization.—Land utilization on the yellow podzolic soils is largely the same as on red podzolic soils. However, forests of exotic trees, largely *Pinus* spp., are more widely produced on yellow podzolic soils.

15. *Meadow Podzolic Soils*

Fig. 15

Morphology.—In meadow podzolic soils the superficial A_{00} and A_0 horizons are frequently absent or the A_{00} nearly so, especially under savannah woodland conditions. The A horizon is grey, darkened by organic matter in the A_1, frequently to a depth of 8-10 in., and light grey in the A_2. Textures are generally sand or sandy loam, but loams do occur infrequently. The B horizon is usually fine-textured, coarsely structured, and mottled in colour, the proportion of brown, grey, and red varying from soil to soil and with depth in the profile. Sometimes there is a little darkening by organic matter of the outside of the structural units of the top of the B horizon, and ferruginous and manganiferous concretions are generally found in that portion of the profile. The C horizon is very variable in character. For portion of the year at least the solum is invaded by a water-table.

The profile illustrated in Figure 15 is a meadow podzolic soil from Kalangadoo, in South Australia. It shows the general nature of the A horizon, the concretionary material, and the mottled clay of the B horizon.

Genesis.—As in the podzolic soils, the texture differentiation of the A and B horizons of the meadow podzolic soils is considered to be due to the eluviation of the clay. The mottled character of the B horizon is due to the varying conditions of oxidation and reduction associated with the periodic invasion of the profile by the water-table. Despite the presence of this water-table for intermittent periods the profile is on the whole effectively leached so that lime is removed from the solum and exchangeable cations are generally moderately low.

Meadow podzolic soils have essentially the same genetic relationships to the soil-forming factors as the podzolic soils, with the addition of the pronounced effect of the water-table. Such effects are facilitated and enhanced by suitably low physiographic position. Parent materials and vegetation associations are greatly

varied but these soils occur in regions of sufficiently humid conditions to ensure the podzolization process. The soils are generally in harmony with current climatic conditions.

Occurrence.—Meadow podzolic soils occur generally in low sites subject to water-table influence throughout the podzol and podzolic soil regions of Australia, that is, in the humid parts of all States.

Utilization.—In southern Australia these soils are used extensively for sown pastures, which are frequently used for the grazing of dairy cattle. They are among the most productive of the podzolic soils, particularly where there is control of the winter-time water-table by artificial drainage. Accessory cultivated crops such as potatoes, oats, and other fodder crops are also of importance on these soils.

16. *Krasnozems*

Fig. 16

Morphology.—Krasnozems, often widely referred to as red loams, and latterly as latosols in the U.S.A., are essentially red to yellow-brown, deep, friable, clay soils showing very little horizon development beyond the accumulation of organic matter in the A horizon. Although generally a clay in texture throughout the profile, the surface soil, because of its organic matter content and the flocculated nature of the clay, has the tilth usually associated with a loam, and the B and C horizons of granular and nutty structure also have a very porous and friable character. Occasionally in the profile will be found small manganiferous and ferruginous concretions.

The profile illustrated in Figure 16 is from near Innisfail, in Queensland. It shows characteristic colour, structure, and the lack of pronounced horizon development usually found in these soils.

Genesis.—These soils lack significant profile development because of the flocculating effect of their high content of hydrated ferric oxide, which minimizes the movement of their generally kaolinitic clay by normal eluvial processes.

Krasnozems occur under generally humid conditions but their relationships to various parent materials are quite complex. In humid areas of low to moderate temperatures they occur only on highly weatherable ferruginous rocks such as basalt, while in humid tropical areas they occur on practically all but the most siliceous rocks, weathering rate under tropical conditions being fast enough to release sufficient hydrated ferric oxide to maintain soil flocculation.

Occurrence.—Krasnozems occur in the eastern Australian States from Tasmania to Queensland but appear with increasing frequency in tropical coastal areas. There are very minor occurrences in the more humid parts of South Australia and Western Australia and on Norfolk Island.

Utilization.—Because of their friable nature and initially high fertility these soils are favoured for a wide range of agricultural crops and pastures. In Queensland a large portion of the sugar-cane crop is grown on them and the peanut-growing industry is also largely located on them. In southern areas they are

favoured for root crops, particularly potatoes, and oats and other cereal crops. Sown pastures of various clovers and grasses are widespread on these soils and are used to a large extent for the grazing of dairy cattle. The initial high fertility of these soils and desirable pasture composition are difficult to maintain but even so they are amongst the most fertile of the arable soils of the more humid eastern agricultural areas.

17. *Lateritic Krasnozems*

Fig. 17

Morphology.—The surface and subsurface horizons of the lateritic krasnozems are essentially the same as in their non-lateritic counterparts. However, at some depth in the profile there is found a variable horizon of laterite, massive and pisolitic, fragmentary and diffuse, or porous and vermicular. The laterite horizon varies considerably in thickness and is normally underlain by mottled and pallid zones of kaolinitic clay. Parent material appears to be variable and to have the same general relationships to the profile as in the non-lateritic krasnozems.

The profile illustrated in Figure 17 is from Toowoomba, in Queensland. It shows an unusually thick accumulation of laterite in a krasnozem soil.

Genesis.—Although these soils have not been recorded in association with a water-table it seems certain that, as in lateritic soils generally, they have had such an association and that the laterite and its companion materials are of hydrogenic origin. There is some evidence, more particularly from Africa, that the formation of laterite in krasnozems does not require quite so significantly subdued relief as in lateritic soils of a more podzolic character. Nor are they necessarily of Pliocene age; in fact they occur on some igneous rocks of younger geological age.

Occurrence.—Small areas of lateritic krasnozems are found intermingled with normal krasnozems in some of the districts of coastal and subcoastal Queensland.

Utilization.—The little information that is available indicates that these soils have similar, if not identical, uses to the non-lateritic krasnozems.

18. *Lateritic Red Earths*

Fig. 18

Morphology.—Lateritic red earths are red to light red soils with a deep profile containing a horizon of laterite with mottled and pallid kaolinitic horizons beneath. The A horizon is commonly sandy to loamy in texture and darkened with a little organic matter. It passes gradually into a slightly finer-textured B horizon, which is usually a bright red in colour, and of compact but somewhat vesicular structure. The horizon of laterite is found at various depths and it is of variable character, nodular, pisolitic, vermicular, or massive. The mottled and pallid horizons beneath the laterite are variable in depth and may occasionally be missing. Frequently they contain a siliceous horizon of "billy". These soils are found on a wide range of parent materials.

The profile illustrated in Figure 18 is from Mataranka, in the Northern Territory. It shows the laterite horizon about 3 ft from the surface and the mottled zone in the bottom of the cutting.

Genesis.—Lateritic red earths are largely associated with relict land surfaces, probably of Pliocene age. General evidence indicates that these soils were formed under peneplain conditions in association with a fluctuating water-table, which was largely responsible for the development of the lateritic and kaolinitic horizons of the profile.

Occurrence.—Lateritic red earths are confined to tropical and subtropical Australia; they are not found in the more humid temperate areas of southern Australia, where their normal position in the landscape is occupied by lateritic podzolic soils.

Utilization.—These soils are a common feature of the tropical savannah woodland and cattle-grazing areas of northern Australia, where all utilization depends on the prevalence of native grasses and other edible plants. To a very limited degree around Darwin and to a larger extent around Brisbane these soils have been developed for horticultural purposes, both vegetables and tropical fruits being readily produced. With adequate fertilizer and the use of irrigation water in the dry winter and spring months they are quite productive.

19. *Terra Rossa Soils*

Fig. 19

Morphology.—A terra rossa, as the name indicates, is essentially a red earth. Actually these soils range from reddish brown to red in colour, are generally shallow in depth, and occur exclusively on limestone as parent material. They range in texture from sandy to clayey. In the lighter-textured members there is usually some horizon differentiation, but in the clay loam and clay members profiles are characterized by a generally granular and nutty structure in the A and B horizons respectively rather than by horizons of marked textural contrast. In some profiles there occur small amounts of ferruginous concretions in the B horizon, but these are not a consistent feature of terra rossa.

The profile illustrated in Figure 19 is from Coonawarra, South Australia. It is a medium-textured soil and shows slight change of structure in the depth of the profile.

Genesis.—Although the simultaneous occurrence of rendzina with terra rossa is not universal, they are found very frequently together. Evidence so far indicates that terra rossa soils are confined to the harder sorts of limestone and rendzinas to the softer. Why this is so is not clearly understood.

Terra rossa soils are found on appropriate parent material under a fairly wide range of climatic conditions in humid to subhumid localities, particularly where there is a marked seasonal incidence of rainfall. Where under local conditions drainage is restricted, they are replaced by ground-water rendzinas. They are replaced by brown forest soils in temperate and subtemperate regions. The soil is developed essentially on the residues left after the solution and leaching away of the parent limestone.

Occurrence.—Terra rossa soils are not common in Australia but they are of frequent occurrence in the lower south-eastern district and in the foothills area

of Adelaide, in South Australia. They have also been seen sporadically in small areas in Victoria and New South Wales.

Utilization.—Owing to their scattered distribution amongst soils largely used for pastures, terra rossa soils are predominantly used for that purpose. Both natural and sown pastures are common. In limited areas they are used for horticultural purposes, more particularly for tree and vine fruits.

20. *Prairie Soils*

Fig. 20

Morphology.—Prairie soils are most frequently deep formations with dark-coloured surface horizons, without lime in the solum proper, i.e. in the A and B horizons, although it may be present in the lower C horizon when the parent material is calcareous. The A and B horizons are acid to neutral in reaction. The A horizons, which contain appreciable amounts of organic matter, vary in texture from loams to clays, are dark grey or grey-brown to black in colour, and are of crumb to nutty structure. The B horizons, contrasting somewhat with the surface soils, are invariably clays of nutty to coarse blocky structure and brown to yellow-grey colour, often drab, and sometimes, in moister situations, slightly mottled. Parent materials vary from alluvium to a variety of the more basic rocks.

The profile illustrated in Figure 20 is from near Lismore in northern New South Wales. It rests on basalt.

Genesis.—The moderate contrast in texture between the A and B horizons of these soils and their acid to neutral reaction is due to a weak but effective leaching of the relatively basic materials on which they are found by the moderate rainfall of their climatic environment. The effectiveness of this leaching precludes the presence of lime in the A and B horizons although it may not be intense enough to remove parent material lime from the lower part of the C horizon. The relative intensity of the leaching factor and its modification by the basicity of the parent material and the fine texture of the profile are the determining factors in the development of prairie soils or black earths as described below.

Occurrence.—Prairie soils are found most commonly in parts of coastal and subcoastal New South Wales, and in smaller areas in moist to subhumid areas in Tasmania, Victoria, and South Australia, the one noted instance in the latter being confined to the Mt. Barker district in the Mt. Lofty Ranges.

Utilization.—Prairie soils are relatively fertile and are used for a variety of agricultural and pastoral purposes. They generally support good-quality sown pastures used for dairying and fat lamb raising, and where cultivated produce moderate to heavy cereal and root crops, often with a minimum of fertilizer.

21. *Black Earths*

Fig. 21

Morphology.—Black earths are essentially deep profiles with dark-coloured surface and subsurface soils and with lime in the solum. They normally show some slight degree of textural horizon differentiation, the A horizon being black,

dark grey, or dark brownish grey clay loam or clay of granular to cloddy structure up to 12 in. or more deep, and the B horizon a granular to coarsely structured clay, yellow, brown, or yellowish brown in colour and containing lime in the form of specks, pellets, or concretions. Frequently the lime appears in the darker soil above and often persists below into the C horizon, which is of a very variable character, being determined by the soil parent material, which ranges from alluvium to a large variety of predominantly non-siliceous rocks.

The profile illustrated in Figure 21 is from near Coleraine, Victoria. It shows the characteristic depth and structure of the black upper horizons of the profile.

Genesis.—The generally low contrast in texture of the A and B horizons of black earths is due to the weak leaching effect of the subhumid climate in which these soils are found. This low texture contrast and the presence of lime in the profile are a reflection of the inability of such a climate to leach a relatively heavily textured profile. Parent material is therefore, by its control of soil texture, a genetic factor of major importance in these soils.

Black earths, in common with other pedocals in Australia, are subject to profile and surface contortion known as gilgai or crabhole formation. This takes the form of an irregular pattern of rises and hollows or regular linear mounds and hollows. Presumably these are caused by the entry of surface material down deep cracks, which develop when the soil is dry and close up and cause pressure in the subsoil when wet, the pressure being relieved by heaving of the surface.

Occurrence.—Black earths are found in eastern Australian States, ranging from southern Tasmania to northern Queensland. In South Australia they occur as an occasional minor component along with red-brown earths in the soil landscape. In northern New South Wales and Queensland they are the dominant and red-brown earths the minor component.

Utilization.—Black earths are almost exclusively pasture and wheat-producing soils. For the greater part the pastures grazed by sheep and cattle are natural but in southern Australia sown pastures are relatively common. Under wheat production these soils are amongst the most fertile, their phosphate status in sub-tropical areas sometimes being sufficiently high to preclude a response to applications of superphosphate. They are somewhat subject to erosion, which on arable land is difficult to control by conventional terrace structures.

22. *Wiesenboden*

Fig. 22

Morphology.—Wiesenboden are primarily hydromorphic black earths, that is, soils with essentially black, fine-textured A horizons and calcareous clay B horizons. However, the colours found in the B horizons are dull and generally mottled in some degree, grey being dominant. Periodically a water-table will be found in the subsoil.

The profile illustrated in Figure 22 is from Glen Osmond, South Australia. It shows the mottled and calcareous clay subsoil beneath a black deep surface horizon.

Genesis.—The genesis of wiesenboden is essentially the same as that of black earths but modified in the subsoil by the seasonal presence of ground water, which is responsible for the dull and mottled colours of the B and C horizons.

Occurrence.—Wiesenboden are found in more or less restricted areas in association with black earths and to a less degree in association with podzolic soils and red-brown earths, where they sometimes occur on heavy-textured alluvium in valleys with somewhat restricted drainage.

Utilization.—Wiesenboden are apparently of such restricted occurrence that they are subject to the same utilization as surrounding soils. Normally this is the growing of pastures and cereal crops.

23. *Brown Forest Soils*

Fig. 23

Morphology.—Brown forest soils are calcimorphic, their parent material being highly calcareous and overlain by a generally shallow soil profile. These soils are brown in colour in both the A and B horizons, which are generally of medium to fine texture and with little contrast between them. Soil structure varies from crumb in the surface of the profile to granular and nutty below. Free lime occurs in the lower part of the solum.

The profile illustrated in Figure 23 is from Clarendon, South Australia. The colour, structure, and shallow nature of this profile are shown.

Genesis.—These soils largely owe their morphological features to their calcareous parent material, which, despite the humid conditions under which they occur, maintains a high percentage of calcium in the exchange complex of the soil.

Occurrence.—So far these soils have been definitely identified only in the more humid parts of the Mt. Lofty Ranges near Adelaide, in South Australia. There is reason to believe that they occur on limestone in some of the mesophyllic forests of coastal and subcoastal Queensland.

Utilization.—Where these soils have been seen they are used for both pasture and horticultural crops. Both natural and sown pastures are used and horticultural activity is predominantly the production of wine grapes.

24. *Rendzinas*

Fig. 24

Morphology.—Rendzinas are calcimorphic soils, their profile consisting of shallow black to very dark grey and brown soil resting on limestone. They are generally of medium to fine texture, lack significant development of A and B horizons, and have a pronounced structure varying from crumb and granular in the surface to angular nutty in the subsoil, which generally contains some free lime.

The shallow profile of typical structure illustrated in Figure 24 is from near Kalangadoo, South Australia.

Genesis.—Rendzinas, where they are associated with terra rossa, generally occur on the softer limestone parent materials. However, they occur over a wider

climatic range than the terra rossa but maintain their distinctive morphology because of the influence of the calcareous parent material in ensuring a high calcium status in the ion exchange complex of the soil.

Occurrence.—Where suitable parent materials occur these soils are found in the eastern States of Australia and in South Australia.

Utilization.—These soils are used for both pastures and crops. Pastures are generally of the sown type and crops range from cereals to flax. They are also planted to some extent to wine grapes.

25. *Ground-water Rendzinas*

Fig. 25

Morphology.—Ground-water rendzinas have essentially the same features as normal rendzinas with the addition of a water-table which periodically invades the solum and, for brief periods, may inundate the surface of the soil. The effect of this water-table is not very pronounced morphologically, the undifferentiated texture, structure, and colour profile remaining largely the same as in normal rendzinas; however, frequently there is some lightening in colour of the clay subsoil to drab yellow-grey or grey in that part in contact with the calcareous parent material.

The profile from Millicent, South Australia, illustrated in Figure 25 shows the general colour and structural characteristics of ground-water rendzinas. The drab-coloured clay associated with the limestone should be noted.

Genesis.—These soils appear to form in essentially the same manner as normal rendzinas and to be but slightly modified by the presence of ground water. Weathering and solution of the parent lime-bearing material, leaving behind a shallow residue of fine-textured material, appear to be the necessary initial stage in the process of rendzina formation.

Occurrence.—So far as is known, ground-water rendzinas occur extensively in Australia only in the lower south-east of South Australia.

Utilization.—These soils are now used practically exclusively for the production of high-quality sown pastures, which are grazed by dairy cattle and sheep. Formerly they were used quite extensively for the production of barley but the availability of high-quality grain from other areas led to a gradual decline in barley-growing on ground-water rendzinas.

26. *Fen Soils*

Fig. 26

Morphology.—Fen soils are neutral to alkaline peats occurring in association with alkaline ground water that periodically rises to a level at or above the surface of the peat. The surface horizon of the peats may be either black and granular, dark brown and coarsely fibrous, or of some intermediate character; occasionally there is a surface deposit of soft lime. The lower horizons of the peat profile are generally black in colour and granular in structure, and rest on calcareous material at a depth of a few feet.

The profile from Eight Mile Creek Swamp, in South Australia, illustrated in Figure 26, shows a profile of a black, granular type of fen peat. The associated water-table and limestone beneath are also shown.

Genesis.—These peats owe their development to the accumulation of organic matter under waterlogged conditions which prevent decomposition of plant residues accumulating from associated dense thickets of trees and from sedge meadows. Debris from the tree thickets gives rise to the black, granular peat, the sedge meadows generate the fibrous material, and under the wettest conditions the calcareous remains of *Chara* and of various Mollusca give rise to shallow, superficial deposits of lime on the peats of the sedge meadows.

Occurrence.—Fen peats have been recognized in the lower south-east of South Australia, where alkaline telluric water emerges from the underlying limestone and is ponded in coastal depressions before draining into the sea.

Utilization.—These soils are in process of being reclaimed by drainage and sown down to high-quality pastures for grazing by dairy cattle.

27. *Solonchaks*

Fig. 27

Morphology.—Essentially solonchaks are saline soils of any description, other morphological features that may be present being considered of minor significance. In primary solonchaks the presence of soluble salts maintains a flocculated soil with no particular textural profile development. In secondary solonchaks the morphology of the original profile prior to salinization may be well preserved; solonchaks then bear strong resemblance to other great soil groups such as podzolic soils, black earths, etc. Frequently the salt present in the soil is not visible but can readily be detected by simple chemical tests. A puffy character in the surface soil and the presence of known salt-tolerant plants are usually good indicators of solonchak soils.

Figure 27 shows a solonchak from near Alice Springs, in the Northern Territory. Salt-tolerant plants, saline surface deposit, powdery surface soil, and damp subsurface soil are all visible.

Genesis.—Any soil material that is or becomes sufficiently saline to influence adversely normal plant growth may be considered as a solonchak. In Australia the soluble salts involved are largely derived primarily from the ocean in the form of wind- and rain-borne cyclic salt, retained for varying lengths of time in the soil profile on which it is precipitated, depending on the amount and seasonal character, and thus the leaching efficiency, of the rainfall. Local drainage conditions, either natural or induced by man, may initiate a redistribution of the salt in soils, thus causing solonchaks to be formed on lower slopes and in valleys and depressions.

Occurrence.—Solonchaks occur in the subhumid and arid parts of all Australian States. Primary solonchaks occur usually in low situations in these areas and secondary solonchaks have developed in both irrigated and non-irrigated farm lands; in the latter particularly in Western Australia, where the clearing of native vegetation from the hills and cultivation have initiated a redistribution of soluble

salts, causing them to give rise to solonchaks in the soils of lower slopes and alluvial valley floors.

Utilization.—Primary solonchaks are used only incidentally for grazing by stock. Secondary solonchaks of irrigated and non-irrigated lands may be abandoned from their former use or attempts at reclamation made.

28. *Solonetz*

Fig. 28

Morphology.—Solonetz soils are essentially characterized by the morphology of the B horizon, which has the form of domed columns. The columns frequently have approximately hexagonal cross sections varying from a square inch or two up to over a square foot, and the upper portions of the sides of the columns are darkened by organic stain. The domes on top of the columns form the upper portion of the B horizon; they can be practically hemispherical in shape and are superficially generally lighter in colour than the columns below. When dry, the domed columns are separated from each other by conspicuous cracks in which A horizon material is frequently found. Solonetz profiles vary in colour from grey to brown and red-brown and there is normally some contrast in texture between the A and B horizons, with lime appearing in the profile in the lower part of the B horizon. C horizons and parent materials are variable.

The solonetz profile shown in Figure 28 is from Bordertown, South Australia. The cracks between the domed columns, which have been cut through, are clearly visible.

Genesis.—The characteristic structure of the B horizon and the contrast in texture between the A and B horizons are the result of sodium ion influence inherited from an incipient or definitely former solonchak state. The contrast in texture is due to eluviation of sodium clay and the domed columnar structure to the shrinking and swelling properties of such clays in the B horizon under periodically wet and dry conditions.

Occurrence.—Solonetz soils occur commonly in southern Australia in subhumid areas. They may occupy extensive areas or be a minor component in the soil landscape. They have also been recorded from coastal and subcoastal areas in Queensland.

Utilization.—Solonetz soils are used extensively for the grazing of natural pastures. Some sown pastures are found on these soils but for the greater part when cultivated they are used for annual crops such as wheat and other cereals.

29. *Solodized Solonetz*

Fig. 29

Morphology.—Solodized solonetz soils are characterized by light grey A horizons darkened by a slight accumulation of organic matter to a shallow depth, and by B horizons bearing a conspicuous resemblance to those of solonetz soils but with the domed structure considerably reduced or modified to an oolitic form. The superficial coating of light-coloured siliceous material on the upper part of the

B horizon is particularly conspicuous and the darkening of the sides of the columns reduced. Lime frequently appears in the profile but generally below the solum proper. C horizons and parent materials are variable.

The profile illustrated in Figure 29 is from the Ninety-Mile Plain, in South Australia. It shows the very bleached A horizon and the irregular shape of the top of the B horizon characteristic of solodized solonetz soils.

Genesis.—These soils are considered to be produced by the leaching of solonetz soils. In this process the sodium ion is partially replaced by hydrogen, with resultant changes in structure, particularly in the upper portion of the B horizon.

Occurrence.—Solodized solonetz occur commonly along with solonetz soils. They are particularly common where the parent material of such soils is of a sandy nature.

Utilization.—Solodized solonetz soils have for a considerable time resisted attempts at intense utilization. Until recent years the grazing of stock on natural pastures of an inferior type or on frequently burned heaths was the prevalent form of land use; and this was accompanied by some grain production at low yielding rates and the grazing of stubble and inferior pastures. Now, when deficiencies of phosphate and trace elements are made good, pastures of subterranean clover and other species are being widely developed in southern Australia. Similar improvement has not yet been achieved where these soils occur in northern Australia.

30. *Soloths*

Fig. 30

Morphology.—Soloths or solods are characterized by profile features strongly resembling those of the podzolic soils. The A horizon is grey to light grey and darkened in the A_1 by organic matter. The B horizon has a strong textural contrast with the A horizon and is darkened by a thin veneer of organic matter on the outside of the coarse structural units that comprise the upper portion of the horizon. C horizons and parent materials are variable.

The profile illustrated in Figure 30 is of a soloth from the south-east of South Australia. It shows the contrast in texture between the A and B horizons and the darkened face of the aggregates of clay in the upper B horizon.

Genesis.—Soloths are the product of a further stage in the leaching of solonetz and solodized solonetz soils, hydrogen largely taking the place of the sodium ion in the B horizon, with the result that it loses the characteristic structure of solonetzic soils.

Occurrence.—Soloths have been recognized in the lower south-east of South Australia in districts with rather higher rainfall than those to the north where solonetzic soils occur.

Utilization.—Improved pastures, largely based on subterranean clover, have been grown with varying success on these soils.

31. *Solonized Brown Soils*

Figs. 31*a*, 31*b*

Morphology.—Solonized brown soils, formerly known as mallee soils, are morphologically a bimodal group of soils characterized by a large accumulation of lime in the profile. One subgroup, the lower-situated, consists of shallow grey-brown to red-brown, medium-textured soils up to 1-2 ft deep over a deep accumulation of lime, which in its upper portion has a nodular or travertine form or both, and is normally of finer texture with depth. The lime is accompanied by significant amounts of clay. The soil above the lime accumulation may be weakly differentiated into A and B horizons. The other subgroup, the higher-situated, is associated with dune formations and consists of deep sandy soils, yellow-brown to red-brown in colour, overlying an accumulation of lime generally neither so abundant nor so strongly nodular or travertine-like as in the other subgroup and accompanied by coarser-textured soil. In the profile above the lime horizon there is generally slight textural and colour evidence of the development of a weak B horizon.

The profiles illustrated in Figures 31*a* and 31*b* show the two kinds of profiles characteristic of the solonized brown soils. They are from Roseworthy, South Australia.

Genesis.—These soils are essentially derived from the highly calcareous material in the lower part of the profile. In the dune soils there has been secondary modification of the landscape by aeolian activity, causing the piling up of seif-like parallel ridges of sandy material derived by deflation from the adjacent soils. The origin of the calcareous material is the subject of a number of hypotheses, including reference to loessial origin, calcareous lacustrine residues, and dissected calcareous land forms of erosional and depositional origin related to associated older calcareous rocks. It is possible, in fact probable that in different areas different origins are involved.

The soil profile developed, apart from the marked secondary modification of the upper part of the lime horizon, is due to solonization by sodium ion activity, texture differentiation being accompanied by a significant percentage of sodium in the exchange complex of these soils.

Occurrence.—Solonized brown soils occur in southern Australia in semi-arid to arid regions, generally in areas with less than 15 in. annual rainfall but occasionally occurring in districts with up to 17 in. per annum.

Utilization.—Solonized brown soils are extensively farmed in southern Australia. The principal crop is wheat, and sheep-grazing is important, largely on volunteer pastures on the wheat-growing land. Wheat yields are not high and wind erosion is common, especially on the soils of the dunes. Under irrigation in the mid Murray valley these soils are productive, particularly under horticulture, including citrus, stone fruits, and vines. The soils of the dunes are much favoured for citrus production. The lower-sited soils are liable to some damage by water-table development and salinity where too much irrigation water is used.

32. *Red-brown Earths*

Fig. 32

Morphology.—In red-brown earths the A horizon is invariably brown to red-brown in colour, usually with little or no apparent differentiation into A_1 and A_2 horizons except for a slight accumulation of organic matter in the A_1. Where incipient podzolization or solonization, or both, are evident the A_2 may be discernibly lighter in colour than the A_1. Textures vary from sand to clay loam but loams, usually of a fine sandy or silty nature, are the most common. Structure, for other than sandy soils, is usually of a weak crumb type under virgin conditions; but this is rapidly reduced under frequent cultivation. Depth varies greatly up to 24 in. but is commonly around 12 in. The B_1 horizon is always brighter and redder than the A horizon and varies from red-brown to red and dark red in colour, sometimes falling off to dark brown or dark red-brown in the lower portion. Texture is always heavier than the A horizon, being most commonly clay, but may be sandy or sandy clay loam in juvenile soils; there is usually a fairly definite boundary with the A horizon. The B_2 horizon consists of similar-textured material, generally browner in colour and containing slight to large amounts of lime in soft or concretionary form or both, which frequently lightens the colour of this horizon. Structure of the B_1 horizon varies somewhat according to texture, but for clay is usually strongly prismatic with marked transverse cracking: this structure is largely replaced by a nutty condition in the B_2. The C horizon is usually overlapped by the lime of the B_2, and consists of weathered parent material of very diverse character, of either a sedentary or transported nature.

The profile illustrated in Figure 32 is a red-brown earth from the Barossa Valley, South Australia.

Genesis.—Profile genesis of red-brown earths is largely expressed in the development of the B_1 and B_2 horizons. The former is due to the eluviation of clay from the A horizon and its deposition lower in the soil profile leaving, however, some of the sesquioxides of iron to give the red-brown colour to the surface soil. The B_2 is caused by bicarbonates produced in the upper portion of the profile being leached to a lower horizon and there precipitated as lime. These processes are dependent on the periodic saturation of the upper profile and downward percolation of soil water.

The genetic relationships of red-brown earths to environmental factors are fairly clear-cut. They occur on a wide variety of parent materials, sedimentary and igneous rocks, alluvium and colluvium, whether calcareous or non-calcareous. They are found generally within the 25- and 14-in. isohyets, these limits varying somewhat according to parent material and efficiency of the rainfall, siliceous rocks and high efficiency lowering the 14-in. limit. Relief is not an important factor as these soils are found on hilltops and slopes and in valleys, but free drainage is necessary, otherwise they are replaced by hydromorphic soils. Vegetation relationships are varied in specific character but ecologically they are found in savannah woodland and savannah associations, the grass species doubtless being largely responsible for their organic matter content. They are genetically compatible

with current climatic conditions in the areas of their occurrence and, where juvenile, their progression is towards maturity unless constantly rejuvenated by natural erosion.

Occurrence.—Red-brown earths are found widely in the subhumid portions of South Australia, Victoria, and New South Wales, with lesser occurrences in Queensland, the Northern Territory, and only sporadically in Western Australia in a zone where, if pedological conditions were normal, they should be dominant.

Utilization.—These soils are the mainstay of the wheat-growing industry of southern Australia for which, with accessory sheep-grazing on fallows and volunteer pastures, they are highly developed. They are liable to damage by water erosion, particularly when cultivated on a narrow rotation.

In New South Wales, in the Riverina, and Victoria, they are frequently irrigated, when they are successfully used for both sown pastures and horticultural purposes.

33. *Brown Earths*

Fig. 33

Morphology.—In the brown earths there is an overall resemblance to the red-brown earths except that red tones are either missing or very subdued. The A horizon is dark brown in colour and contains a noticeable amount of organic matter; it is generally about 8 in. or less in depth, of medium to fine texture, and of crumb to nutty structure. The B_1 horizon consists of nutty-structured clay, brown to weakly red-brown in colour, and varying in depth up to about 1 ft. The B_2 horizon, which is frequently coincident with the C horizon, contains small amounts of lime, which in some cases can only be found in the fractures of the weathering rock of the lower C horizon.

The profile of a brown earth illustrated in Figure 33 is from Richmond, Tasmania. It shows the characteristic shallowness of these soils on dolerite and the presence of lime in the BC horizon of weathered rock.

Genesis.—Profile development in brown earths follows essentially the same course as in red-brown earths. The lack of redness, particularly in the surface soil, may be the result of the lower temperatures under which these soils are found, dehydration of iron compounds not being so complete; similarly the greater organic matter content is also probably a function of lower temperatures.

Occurrence.—These soils occur extensively in the drier parts of Tasmania in districts receiving an annual rainfall between 18 and 24 in. They are largely found on dolerite, but occur as well on other parent materials. They have been reported from New South Wales.

Utilization.—Brown earths are largely used for grazing sheep on natural or sown pastures. Where they occur relatively free of intermingled skeletal soils they are often cultivated for wheat and oat crops.

34. *Brown Soils of Light Texture*

Fig. 34

Morphology.—As the name indicates, the A horizon of brown soils of light texture is of a coarse nature, being usually a brown sand or sandy loam with little apparent organic matter. The change from the A to the B and C horizons is usually imperceptible, texture gradually rising to sandy clay loam, sandy clay, or clay and with a compact but somewhat vesicular structure becoming increasingly apparent with depth. Small quantities of lime in the form of soft flecks and occasional nodules may appear in the lower part of the profile, usually some feet below the surface. The colour of the B horizon is red-brown to red and this tends to lighten at some depth into the C horizon, which is variable in character.

The profile illustrated in Figure 34 is a brown soil of light texture from Elliott, in the Northern Territory. The featureless nature of the profile is quite apparent.

Genesis.—The position most frequently occupied on the land surface by brown soils of light texture, namely on low rises and peneplain remnants, may indicate that they are relict soils inheriting at least some of their characteristics from earlier geological eras. Their acid reaction, particularly in the upper part of the profile, and low accumulations of lime in the profile would support such a hypothesis and indicate that they owe their profile characteristics to stronger leaching than that to which they are now subject in their present semi-arid environment. Some profiles bear distinct resemblances to red earths without laterite and except for the lime sometimes found in the profile, which may be of loessial or other subsequent origin, and except for the arid environment would be classified as such.

Occurrence.—Brown soils of light texture are found in the semi-arid parts of the Northern Territory, New South Wales, Queensland, and Western Australia. In New South Wales they have a practically exclusive association with the Cobar peneplain and its northward extension into southern Queensland.

Utilization.—These soils are used practically exclusively for the grazing of cattle and sheep on natural pastures.

35. *Calcareous Red Earths*

Fig. 35

Morphology.—As their name implies, these soils have the characteristic morphology of red earths but include a horizon of lime accumulation. They are usually deep soils, bright red in colour, sands or sandy loam at the surface rising gradually in texture with depth to sandy clay loam. The surface is usually structureless but the remainder of the profile is of a compact, vesicular nature. Except for the lime horizon they are acid in reaction. The lime horizon, in which the accumulation is slight to moderate, is invariably some feet below the surface; it may be partially nodular. These soils rest on a variety of parent materials including detrital material and sedimentary and igneous rocks. Mottled and pallid-zone materials sometimes lie beneath the red earth and calcareous horizons.

The profile illustrated in Figure 35 shows the calcareous material about 4 ft below the surface. It is from Connor's Well, about 60 miles north of Alice Springs in the Northern Territory.

Genesis.—There has been no detailed study of these soils but from their acid reaction and negligible horizon development it is presumed they are polygenetic, representing red earths formed in a wetter climatic era and later invaded by calcium carbonate. Their occurrence on extensive flat to gently undulating terrain, geomorphologically senescent and only slightly above the drainage system, lends weight to this hypothesis. The origin of the lime is obscure; it could be due to loessial additions, temporary invasion of the profile by ground water, or, less probably, continued weathering of soil materials and accumulation of lime under the prevailing arid climate. The very low silt content of the soil reduces the probability of the lime being due to additions of loess.

Occurrence.—Calcareous red earths occur in the more arid parts of Australia, most commonly in the north of Western Australia, in western Queensland, and in the southern and central parts of the Northern Territory. There is some extension of them into the north of South Australia and isolated occurrences have been seen in the goldfields area of Western Australia.

Utilization.—Except for the isolated occurrences noted in Western Australia where sheep are grazed, these soils support only sparse cattle-grazing.

36. *Grey Calcareous Soils*

Fig. 36

Morphology.—The A horizon of these soils consists of a shallow grey or grey-brown, calcareous, medium-textured soil of weakly developed structure, powdery when dry. The weakly developed and shallow B horizon is a dark grey-brown to nearly black, granular to nutty-structured clay loam to clay containing fragments of lime. The C horizon consists of modified calcareous rock. These calcimorphic soils are morphologically clearly related to rendzinas but lack the characteristic colour and structure of such soils.

The profile illustrated in Figure 36 shows the characteristic colour and structure of these soils. It is from Tapley's Hill, South Australia.

Genesis.—Grey calcareous soils are produced by weathering and leaching of calcareous parent material, the soil consisting largely of non-calcareous residue remaining after leaching has removed the greater part of the lime, leaving a shallow accumulation of mineral matter. The grey colour and powdery structure of the surface soils are apparently due to a low accumulation of organic matter, greater accumulation being prevented by high temperatures in the districts in which these soils are found.

Occurrence.—Grey calcareous soils are commonly found in South Australia, occurring on highly calcareous parent material in the districts largely occupied by red-brown earths. Occasional profiles have also been seen in Queensland and Western Australia.

Utilization.—These soils, which normally occur in small areas, are used in the same manner as red-brown earths for wheat-growing and sheep-grazing.

37. *Grey Soils of Heavy Texture*

Fig. 37

Morphology.—The profiles of grey soils of heavy texture, as the name implies, have a morphology dominated by the clay fraction, all horizons being of fine texture. The surface soil, an incipient A horizon, is grey to light grey in colour, a clay loam or clay in texture, coarsely structured, and shallow in depth. The B_1 horizon consists of some depth of grey clay, blocky or massive in structure, and the B_2 horizon of much the same material with small amounts of lime or small to medium amounts of gypsum, or both, present, and frequently showing slight mottling in dull colours. C horizons are variable but consist mainly of weathered fine-textured, alluvial material. In periods of prolonged dry weather the whole soil profile may be traversed by a pattern of cracks, usually nearly vertical, an inch or two in width. Where these soils are affected by gilgai formation lime or gypsum, or both, may occur throughout the profile.

The profile of a grey soil of heavy texture illustrated in Figure 37 is from the Barkly Tableland, Northern Territory. It shows the characteristic colour, structure, and cracking of these soils.

Genesis.—These soils are essentially weakly hydromorphic soils of the semi-arid regions. Because alluvial plains provide the necessary fine-textured material and the occasional flooding required to produce hydromorphic characteristics without sufficient leaching of the profile to remove lime and gypsum, these soils are found under semi-arid and arid conditions on plains subject to intermittent inundation or saturation.

Occurrence.—Grey soils of heavy texture occur on the lower portions of the alluvial plains of the major rivers and seasonal watercourses that traverse inland Australia and on widespread plains such as the Barkly Tableland of the Northern Territory and Queensland.

Utilization.—Until recent years these soils were used exclusively for the grazing of sheep and cattle on natural pastures. In more recent times rice has been grown under flood irrigation on them in the Riverina, in New South Wales. Attempts to grow seeded pastures under irrigation have not so far been particularly successful.

38. *Brown Soils of Heavy Texture*

Fig. 38

Morphology.—Brown soils of heavy texture, like their grey counterpart, are dominated by the fine texture of the profile. The A_1 horizon is brown to grey-brown in colour, and a coarsely structured loam, clay loam, or clay in texture. There may, at a shallow depth, be an incipient A_2 horizon, indicative of some slight solonization. The B_1 horizon consists of a brown, coarsely- or massive-structured clay and the B_2 horizon of similar material, very slightly mottled and

containing small amounts of lime and gypsum. The C horizon consists of fine-textured alluvium. In periods of prolonged dry weather the whole soil profile may be traversed by cracks, generally on the average neither so wide nor so deep as in the grey soils of heavy texture. They are frequently modified by gilgai formations.

The profile of a brown soil of heavy texture illustrated in Figure 38 is from the Barkly Tableland, Northern Territory. It shows the characteristic colour, structure, and cracking of these soils.

Genesis.—These soils are essentially weakly hydromorphic and occasionally halomorphic soils of the semi-arid regions. Like the grey soils they owe their genesis to fine-textured material occasionally flooded or saturated without significant leaching. In the brown soils their position on slightly higher situations modifies the hydrologic process so that brown colour is developed and mottling effects in the subsoil are minimized.

Occurrence.—Brown soils of heavy texture occur on the slightly better-drained portions of the alluvial plains of the major rivers and seasonal watercourses that traverse inland Australia and on the widespread plains of the Northern Territory and Queensland.

Utilization.—These soils are used in precisely the same manner as the grey soils of heavy texture.

39. *Desert Loams*

Fig. 39

Morphology.—Desert loams usually have shallow A horizons brown to red in colour with textures varying from loam to clay, and structure from granular to blocky. Frequently there is some sign of solonization in a light red-brown A_2 horizon and this is accompanied by some indication of domed structure in the upper part of the B_1 horizon, which consists of a coarsely granular to blocky red clay. The B_2 horizon, which contains some lime and gypsum, is a red-brown clay of variable structure and merges into the C horizon. Parent materials consist usually of alluvial material, which is often quite stony. Frequently the surface of desert loams carries a variable pavement of stones or a rather superficial layer a fraction of an inch thick of coarse sand, which is sometimes piled by wind action around the bases of shrubs and grasses.

The profile of a desert loam illustrated in Figure 39 is from Mt. Eba Station, South Australia. It shows the characteristic features described above.

Genesis.—Desert loams, as indicated by the name, occur in the arid portions of Australia where rainfall is low. They occupy areas in southern Australia where the rainfall is between 5 and 10 in. per annum. The low contrast in texture between the A and B horizons is due to the practically inoperative leaching effect of the climate, texture differentiation being due largely to sodium ion activity. The retention of gypsum in the profile also reflects the low leaching power of the rainfall. The surface pavements of sand and stones are due to deflation of the finer soil particles by wind in dry periods and by a normal high rate of erosion

by water action; rain, when it falls, usually having a high intensity and the alkaline and easily dispersed soils a tendency to erode easily.

Occurrence.—Desert loams occur on the wide alluvial plains in the arid regions of Australia, i.e. in all States except Victoria and Tasmania.

Utilization.—These soils are used at low carrying rates for the grazing of sheep and cattle on the rather ephemeral natural herbage and the perennial edible shrubs that comprise various types of shrub steppe characteristic of desert loam soils.

40. *Grey-brown and Red Calcareous Desert Soils*

Fig. 40

Morphology.—Grey-brown and red calcareous desert soils consist of shallow powdery loams to clays with little or no differentiation in the profile. They vary from grey-brown to red in colour and rest at a depth of a few inches on limestone, the upper portion of which may be in the form of travertine. Lime occurs in small fragments and in amorphous form in the soil proper.

The profile illustrated in Figure 40 is from near Urandangie, in Queensland. It shows the featureless nature of the profile.

Genesis.—The soil consists of a simple calcareous residue of mineral matter left from the weathering of the parent limestone. The low rainfall of the area in which the soils are found precludes any significant profile formation other than the partial removal of lime from the soil and the occasional formation of travertine on the upper part of the parent rock.

Occurrence.—These soils occur extensively on the Nullarbor Plain of South and Western Australia and less commonly in other parts of the arid regions of Australia generally.

Utilization.—Sheep and cattle are grazed at low carrying rates on the shrubs and grasses found on grey-brown and red calcareous desert soils, particularly where they occur intermingled with other desert soils. A large part of the Nullarbor plain, the most extensive area of these soils, is unused.

41. *Red and Brown Hardpan Soils*

Fig. 41

Morphology.—Red and brown hardpan soils have a simple profile consisting of a shallow depth of red soil sharply overlying a very indurated hardpan of variable depth. On the surface of the soil there is commonly a scatter of polished rounded stones or "gibbers" darkened by desert varnish. The profile commences with a sand or sandy loam texture and continues without appreciable horizon differentiation to sandy clay loam at or before the abrupt surface of the hardpan, which lies usually from a few inches down to more than 4 ft below the surface. The soil is bright red throughout and, below the loose surface, has a somewhat compact vesicular structure. The pan is very hard, coarsely laminated, dark red or brown in colour, often streaked with black, and varies from a few inches to many feet in thickness. The soil is always acid in reaction but in some instances the pan

contains a little lime in the upper laminar interstices. Where the lime is absent from the upper portion of the pan, as is most frequently the case, its presence below is difficult to detect because of the great hardness and depth of the pan and the lack of deep road and railway cuttings on the flat terrain. The pan contains waterworn siliceous sand and grit and often small rounded fragments of laterite, the whole strongly cemented by secondary silica. When broken with a steel implement it exhibits a rather light-coloured fractured surface. From the nature of the coarser fraction incorporated in the pan and the soil above, the parent material of all profiles appears to be detrital material but in some instances weathered material from various rocks can be found below the pan.

The profile illustrated in Figure 41 is from near Wiluna in Western Australia, about the centre of a very large area in which these soils are greatly predominant and the only area in which they are known to occur. It shows the soil above the pan and about 3 in. of the pan below, this having been penetrated with a crowbar.

Genesis.—The region where these soils occur is quite arid, but occasionally extremely heavy and prolonged rains occur, saturating the soil above the hardpan to above field capacity and extensively flooding the rather flat landscape. On this landscape occur isolated remnants of a higher lateritic surface. These take the form of small flat-topped residuals and hills about 100 ft high variously reduced to the laterite, mottled zone, or siliceous horizons. The flooding and saturation of the soil are presumed to be responsible for the leaching and acidification of the upper true soil horizons and the deposition of the leached silica in the hardpan in which secondary deposits of material are readily seen with the aid of a hand lens. It has been suggested that the pan is the weathering remnant of the siliceous duricrust of the older lateritic profile but it bears so little physical resemblance to this material and occurs so far below well-preserved remnants of that formation that the first hypothesis appears the more tenable.

Occurrence.—These soils occur in an extensive region in central Western Australia centered around Meekatharra and Wiluna.

Utilization.—Red and brown hardpan soils are used almost exclusively for the grazing of sheep on mulga bushes and associated shrubs and ephemeral species at very low carrying capacities. There is a little ancillary beef-cattle grazing.

42. *Desert Sand Plain Soils*

Fig. 42

Morphology.—Desert sand plain soils have the general morphology of lateritic red earths except that the portion of the profile above the laterite is coarse-textured. The immediate surface soil is composed of brown to red loose sand and this is underlain at shallow depths by red-brown to red sand, which may become a little finer-textured and slightly compact with depth until at depths up to about 3 ft a horizon of lateritic gravel is encountered. Below the laterite occur mottled and pallid zone materials. In a proportion of profiles the lateritic gravel is found in the surface soil and in others lime in varying amounts can be found in the lateritic and lower horizons.

The profile illustrated in Figure 42 shows the upper sandy horizons and the lateritic gravel in a desert sand plain soil from south of Rockhampton Downs, in the Northern Territory.

Genesis.—Desert sand plain soils appear to be modified lateritic red earths. They occur on flat to gently undulating terrain, which probably comprises an old land surface inherited from a former moister climatic era. The upper horizons, particularly the surface sand, have most probably been coarsened in texture by deflationary processes associated with the arid climatic conditions under which these soils are now found. There is some evidence of incipient dune formation. The presence of lime in at least some of the profiles may be due to deposition of loessial lime, its solution and redeposition in the profile, or to ground-water action.

Occurrence.—Desert sand plain soils occur in the arid regions of Western Australia, Queensland, and the Northern Territory. In the last they are particularly extensive.

Utilization.—To a limited extent cattle are grazed at low carrying rates on the spinifex and other natural vegetation of these soils.

43. *Calcareous Lateritic Soils*

Fig. 43

Morphology.—Calcareous lateritic soils have the characteristic features of lateritic soils with the addition of an abundance of lime associated with the laterite proper or occurring just below it. The soil above the laterite is grey-brown to red in colour, usually coarse to medium-textured, structureless, and shallow in depth. The laterite below is often of considerable depth, up to 4 ft or more, and characteristically nodular and pisolitic. The lime is contained to a greater or less degree in the interstices of the laterite, or masks the mottled and pallid-zone material below.

The profile illustrated in Figure 43 is from the southern part of the Northern Territory. It shows the lime in the lower part of a deep laterite horizon which lies beneath a shallow surface soil.

Genesis.—It is presumed that, as with the calcareous red earths, the calcareous lateritic soils are polygenetic, having been formed by calcareous invasion of an earlier-formed lateritic soil.

Occurrence.—These soils have been seen sporadically in parts of the Northern Territory ranging from the southern fringe of the Barkly Tableland to the northern approaches of the Macdonnell Ranges, also between Kalgoorlie and Coolgardie in Western Australia and on Eyre Peninsula in South Australia.

Utilization.—In the Northern Territory these soils support sparse cattle-grazing, in Western Australia sparse sheep-grazing, and in South Australia more intense grazing of sheep on sown pastures of short-season strains of subterranean clover and other species.

44. *Stony Desert Tableland Soils*

Fig. 44

Morphology.—Stony desert tableland soils are found on characteristic tableland relics of a former landscape, their surface being covered by a pavement of broken and polished siliceous stones. Beneath the stony surface lies an A horizon of loam to clay texture, brown to red-brown in colour, shallow in depth, and frequently showing slight effects in a paler incipient A_2 horizon of some solonized character. The B_1 horizon consists of red-brown to red coarse-structured clay, and gypsum with possibly a little lime appears in the B_2 horizon of lighter-coloured massive clay. Weathered C horizons and parent materials of the original soil are variable.

The profile illustrated in Figure 44 is a stony desert tableland soil from the north-west pastoral country of South Australia. The stony surface pavement and the gypsum of the subsoil are quite apparent.

Genesis.—These soils are essentially modified truncated residuals of former soils from which the upper horizons have been removed. The siliceous material, which is a relic of a former soil horizon, and the general paucity of lime in the profiles as now found indicate a genesis in a period of greater leaching power than the arid climate now prevailing. The precursor soils probably were formed in the pluvial periods of the Pliocene and exist today only as truncated remnants following the general uplift and dissection of an Australian peneplain in Pleistocene and Recent times.

Occurrence.—These soils are found on the slopes and flat tops of tableland residuals generally throughout arid Australia, thus embracing parts of Queensland, New South Wales, Western Australia, South Australia, and the Northern Territory. They are particularly prominent features in the Lake Eyre basin.

Utilization.—Cattle and sheep are grazed at very low carrying rates on the sparse shrub steppe vegetation found on these soils.

45. *Desert Sandhills*

Fig. 45

Morphology.—Desert sandhills have soils composed of deep, partly mobile sands with only the slightest evidence of profile development. The profile is red in colour and sandy in texture throughout, with a tendency to compactness with depth. A little lime may be found some depth below the surface.

The profile illustrated in Figure 45 is from the north-west pastoral country of South Australia. It shows the typical red, sandy nature of the profile of desert sandhills and the slight compaction of the deeper part of the profile.

Genesis.—Desert sandhills, which are normally of the seif type, are composed of deflated residues of coarse-textured material piled into partly stabilized dunes. The siliceous nature of the sand, and the dry climate, preclude any great degree of profile development beyond the compaction of the lower part of the profile and modification of the little lime that may be present.

Occurrence.—Desert sandhills occur extensively in a number of areas of extreme aridity, notably in the Simpson Desert, south of the Macdonnell Ranges in central Australia, and in the northern portion of Western Australia. They also occur with varying frequency along with desert loams and other arid soils in various other arid localities.

Utilization.—Where they occur in extensive areas desert sandhills are not grazed by stock except along the fringes. Where they occur with desert loams and other soils their vegetation is grazed along with that of the other soils. Carrying capacity is low and there is a marked liability to wind erosion.

Gilgai or Crabholey Soils

The following note on "gilgai" or "crabholey" formations in soils indicates the general character of this phenomenon. The surface of the soil exhibits an undulating microrelief, mounds and depressions occurring over distances of a few yards. The vertical distance between crest and hollow may be only 1-2 in. or as much as several feet. The soil profile in the hollow is generally complete with characteristic A horizons whilst that on the crest or "puff" is generally truncated with obvious B horizon material exposed on the surface.

Degradation of Soil Profiles

Fig. 46

Under certain circumstances soils with B and C horizon morphology characteristic of one of the great soil groups show atypical A horizon features. This phenomenon, in which the A horizon is generally grey, is referred to as a degradation. It is possibly due to the onset of podzolization or solonization, or both. An example of a degraded black earth from Lawrenny in Tasmania is shown in Figure 46. The grey A horizon on top of a characteristic subsurface and subsoil profile of a black earth provides a strong contrast with the usual dark-coloured and structural surface soils of normal black earths.

III. A Bibliography of Modern Australian Soil Surveys and Related Investigations

(Selected in part from a general bibliography prepared by E. A. Jackson)

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PLATES

Fig. 1.—Alluvial soil.

Fig. 2.—Skeletal soil.

Fig. 3.—Aeolian sand.

Fig. 4.—Moor peat.

Fig. 5.—Alpine humus soil.

Fig. 6.—Moor podzol peat.

Fig. 7.—Acid swamp soil.

Fig. 8.—Podzol.

Fig. 9.—Ground-water podzol.

Fig. 10*a*.—Lateritic podzolic soil.

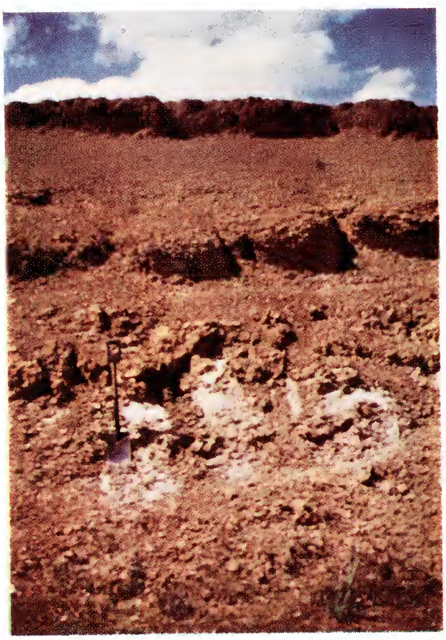

Fig. 10*b*.—Lateritic podzolic soil.

Fig. 11.—Grey-brown podzolic soil.

Fig. 12.—Brown podzolic soil.

Fig. 13.—Red podzolic soil.

Fig. 14.—Yellow podzolic soil.

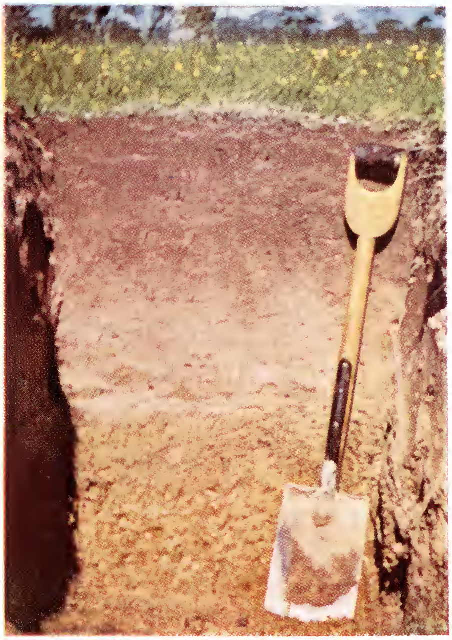

Fig. 15.—Meadow podzolic soil.

Fig. 16.—Krasnozem.

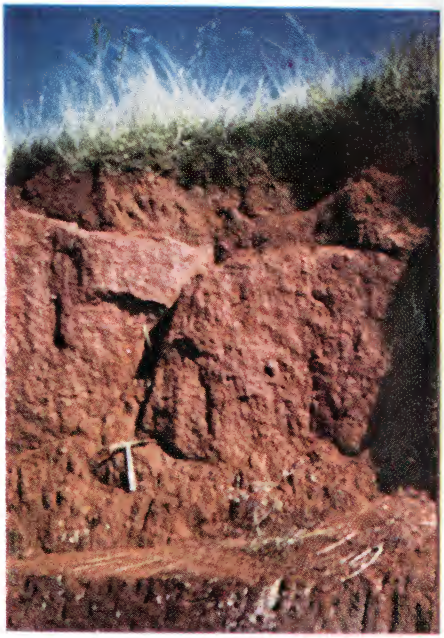

Fig. 17.—Lateritic krasnozem.

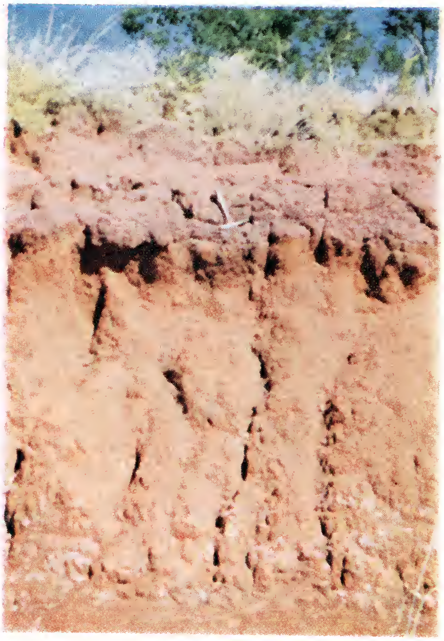

Fig. 18.—Lateritic red earth.

Fig. 19.—Terra rossa soil.

Fig. 20.—Prairie soil.

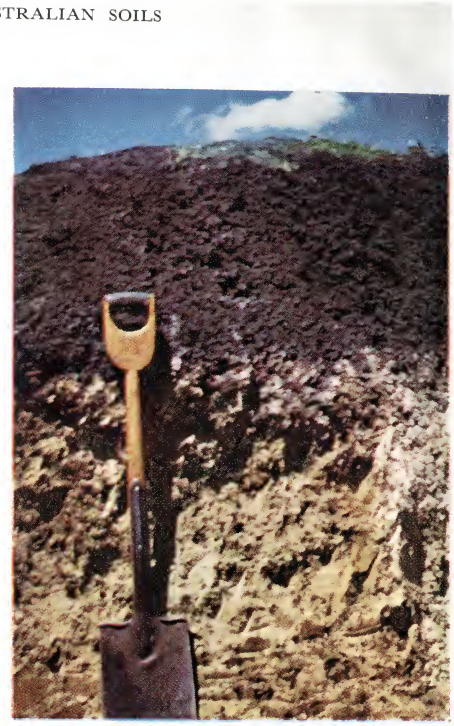

Fig. 21.—Black earth.

Fig. 22.—Wiesenboden.

Fig. 23.—Brown forest soil.

Fig. 24.—Rendzina.

Fig. 25.—Ground-water rendzina.

Fig. 26.—Fen soil.

Fig. 27.—Solonchak.

Fig. 28.—Solonetz.

Fig. 29.—Solodized solonetz.

Fig. 30.—Soloth.

Fig. 31*a*.—Solonized brown soil.

Fig. 31*b*.—Solonized brown soil.

Fig. 32.—Red-brown earth.

Fig. 33.—Brown earth.

Fig. 34.—Brown soil of light texture.

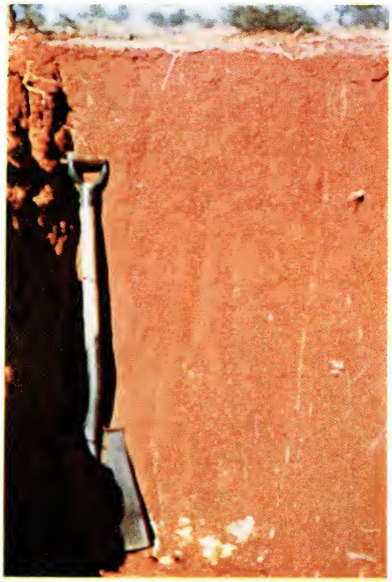

Fig. 35.—Calcareous red earth.

Fig. 36.—Grey calcareous soil.

Fig. 37.—Grey soil of heavy texture.

Fig. 38.—Brown soil of heavy texture.

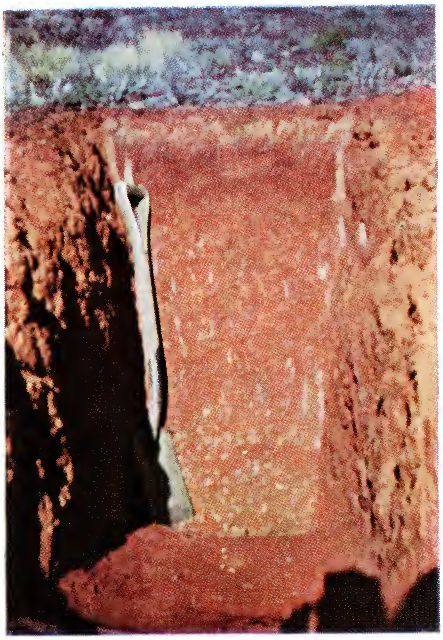

Fig. 39.—Desert loam.

Fig. 40.—Grey-brown and red calcareous desert soil.

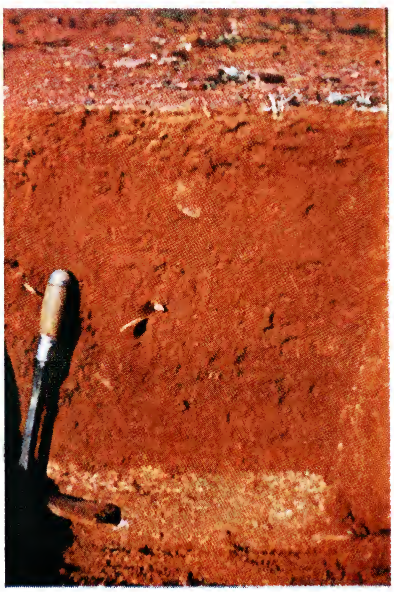

Fig. 41.—Red and brown hardpan soil.

Fig. 42.—Desert sand plain soil.

Fig. 43.—Calcareous lateritic soil.

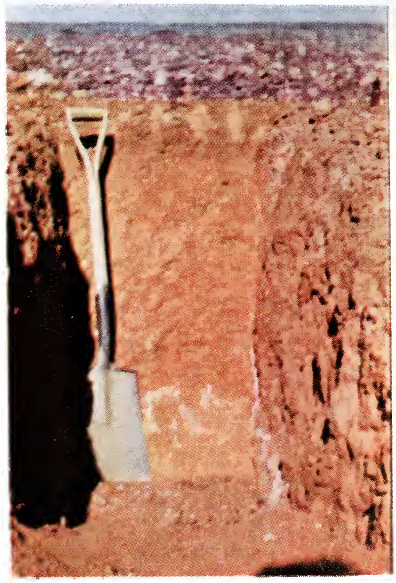

Fig. 44.—Stony desert tableland soil.

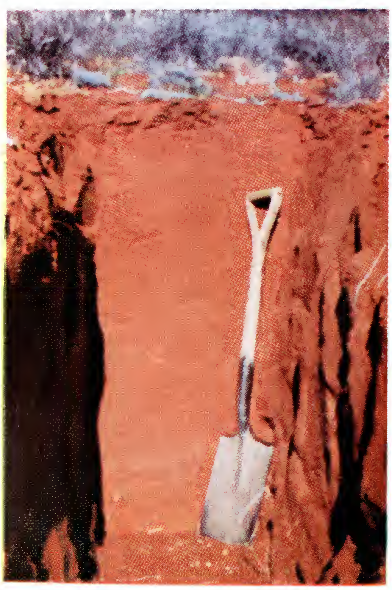

Fig. 45.—Desert sandhill.

Fig. 46.—Degradation of soil profile.